FIVE THINGS LEARNED FROM THE ANTARCTIC SEARCH FOR METEORITES

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Cover photo: Longtime ANSMET mountaineer John Schutt gets a closer look at a meteorite spotted in a moraine on the edge of the blue ice at Davis-Ward. Credit: ANSMET.

FIVE THINGS LEARNED FROM THE ANTARCTIC SEARCH FOR METEORITES

James M. Karner (University of Utah), Ralph P. Harvey (Case Western Reserve University), John S. Schutt (Case Western Reserve University), and Brian Rougeux (Case Western Reserve University)

A half century ago, in 1969, the Japanese Antarctic Research Expedition (JARE-10) found nine meteorites that were several hundred meters to a few kilometers apart, on bare ice that was upstream from the Yamato Mountains. A few years later, at the annual Meteoritical Society meeting, the JARE team reported these nine Antarctic finds to the planetary science community. It turned out that the nine specimens were individual meteorites that were distinct from one another, i.e., they were not just nine pieces of one meteorite that broke apart above the ice or on impact with the ice. Furthermore, four of the nine meteorites were of exceedingly rare class and/or petrographic type — exceedingly rare in the fact that if you found 100 meteorites, only one out of that 100 might be any of those classes or types.

William (Bill) Cassidy, from the University of Pittsburgh, was in the audience for that presentation, and he immediately surmised that four rare meteorite finds out of a total of only nine in a relatively small area was extremely fortuitous, maybe even incomprehensible. Unless — and this was Cassidy's "Eureka!" moment — there were thousands of meteorites on the bare ice areas of Antarctica! Cassidy spent the next few years convincing the National Science Foundation (NSF) to fund a U.S. team to search for meteorites in Antarctica, and finally in 1976–1977 the first Antarctic Search for Meteorites (ANSMET) team recovered nine meteorites from the huge expanses of bare (blue) ice in the Allan Hills area of Antarctica. At present, Cassidy's legacy, the ANSMET program, is a collaboration between NSF, NASA, and the Smithsonian Institution, and has completed its forty-third field season. In those 43 seasons, ANSMET has recovered more than 23,000 meteorites from approximately 65 separate locations (which often include multiple icefields) in East Antarctica.

The continuing goal of the ANSMET program is to recover a complete and representative sample of the extraterrestrial materials falling to Earth and make them available for research. Here are several things we've learned about meteorite recovery in Antarctica and what it means to planetary science.

Meteorites are Found on Slow-Moving or Stagnant Blue Ice that is Being Slowly Ablated Away

Our basic understanding of the genesis of Antarctic meteorite concentration sites (i.e., icefields) is that meteorites have been raining down on the East Antarctic Plateau for several millions of years. They are then buried by snow, and are eventually incorporated into glaciers that flow down through the Transantarctic

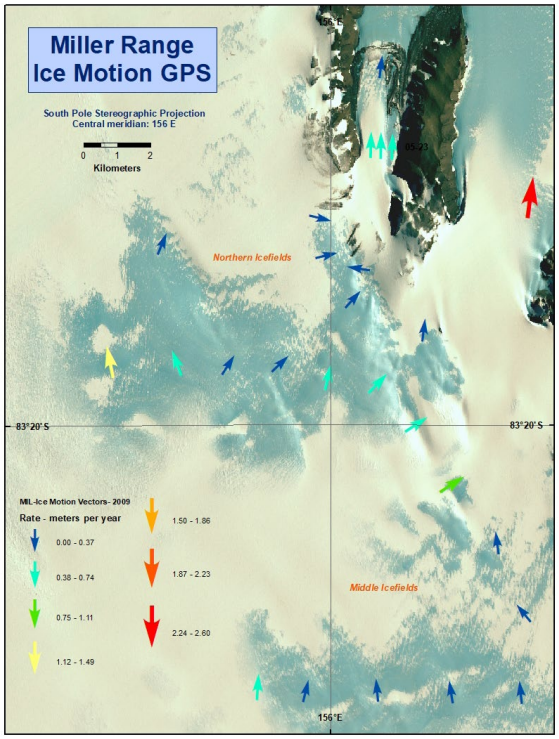

Fig. 1a. Ice motion at the Miller Range. This multi-spectral satellite mosaic shows the blue ice areas of the Northern and Middle Icefields in relation to the exposed peaks of the Miller Range. The dark-colored areas are exposed mountains, whereas the white areas are snow. General ice motion is south to north (from the bottom of the image up); i.e., the ice is flowing down off the polar plateau to the south and running into the Miller Range peaks. The colored vectors denote the specific ice motion and rates measured at each location. Note that most of the ice in the area is moving at a rate of less than 1 meter per year. Credit: ANSMET.

Mountains (TAMS) and eventually empty into the Ross Sea. With general ice sheet thinning over the last 20,000 years, previously unobstructed and rapidly flowing glaciers have been redirected, trapped, and stranded by exposed and subsurface barriers (i.e., the TAMS). Simply put, free-flowing ice has now been pinched off, slowed, and ablated — allowing deep blue ice to be exposed, and meteorites trapped in that blue ice to be exhumed at the surface and accumulate like a lag deposit. Additionally, these blue ice areas have most likely remained stable for tens to hundreds of thousands of years, so they also have "caught" and preserved meteorites that have fallen on them over those extremely long time periods. We call that process direct infall, and it undoubtedly adds to the concentration of meteorites in blue ice areas.

A classic example of a meteorite concentration site where slow-moving ice is being ablated away is the Miller Range icefields (Fig. 1a). The Miller Range icefields are located in the Beardmore Glacier region of Antarctica and are composed of three fairly geographically distinct blue ice areas: the northern, middle and southern icefields. ANSMET teams have spent part or all of eight field seasons searching the three icefields and have recovered more than 3000 meteorites from them — and we still have at least one more season of work there! During the 2005–2006 field season, Gordon Osinski and the rest of the ANSMET team set up an ice movement and ablation study, which consisted of installing two dozen steel posts into the ice at separate locations throughout the area. The idea was to document the post's GPS location and also mark the surface level of the ice on the post. Then, after a few years had passed, we would remeasure the post's location and height of the ice surface level. The results of that study reveal that ice at Miller is moving very slowly, at a speed of less than ~1 meter per year in most cases. And just to give these rates some context, ice in the Nimrod and Marsh glaciers (not shown, but just off the image to the west and east, respectively), is briskly moving along at speeds of tens to hundreds of meters per year. Figure 1b shows that the slow moving ice is being slowly ablated away at an average rate of about 3.5 centimeters per year by scouring katabatic winds, sublimation, and perhaps rare melting events. This combination of slow ice and steady ablation at Miller leads to an optimal setting for meteorite concentration.

Check the Moraines Too

Historically, ANSMET teams have mainly searched for meteorites on the bare, blue ice areas of icefields following a transect-sampling procedure. In this procedure the field team forms a line, each member a few tens of meters to several tens of meters apart (usually on a snowmobile). The team then proceeds to drive across the blue ice in a direction perpendicular to this line, scanning for meteorites as they go. Meteorites are pretty easy to spot — black rocks on light blue ice, and they are also easily distinguished from the small numbers of terrestrial rocks scattered across the blue ice. Searching on blue ice is speedy and relaxed.

Moraines are a different story. They are by definition an accumulation of rocks that have been carried and deposited by a glacier, therefore spotting a meteorite among thousands of terrestrial rocks is definitely not easy. It takes intense concentration, patience, and even luck. Searching in moraines is slow (the search is done on foot) and arduous. But after 43 years of searching, it is apparent that the moraines accompanying icefields (lateral, terminal, medial, etc.) hold significant concentrations of meteorites. For example, in its last two field seasons at Davis Nunataks-Mt. Ward (DW), ANSMET recovered ~760 meteorites from the moraines that surround the icefields. That number amounts to almost 50% of the meteorites found in the area over those two seasons. Moraine searching among thousands of terrestrial rocks is decidedly more challenging than spotting meteorites on blue ice, but the potential payoff in extraterrestrial samples makes it worth the effort (see Fig. 2).

Check the Downwind Ice Edge

The downwind border of an icefield is often characterized by blue ice that gives way to a compact snow called firn. The strong katabatic winds in Antarctica are capable of moving rocks of up to 100 grams, and firn has proved to be an excellent trap for wind-blown rocks and meteorites (see Fig. 3). The meteorites

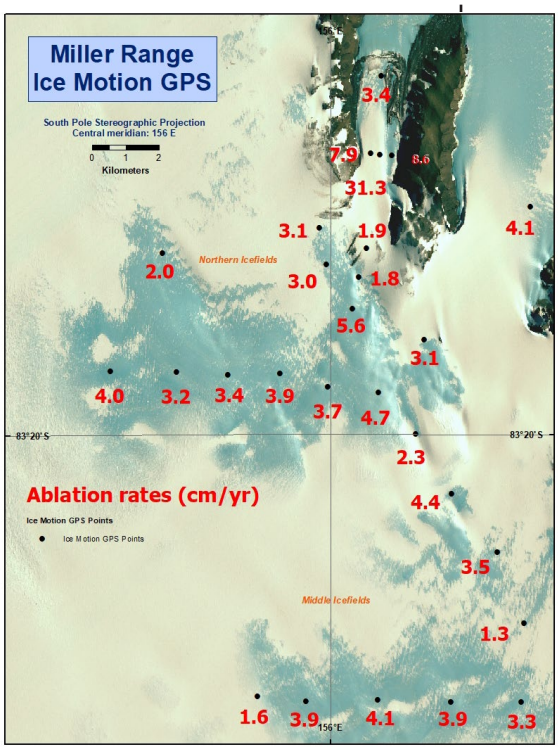

Fig. 1b. Ice ablation rates at the Miller Range. The red numbers denote the ice ablation rates in centimeters per year for the specific locations (black dots). The ASTER satellite imagery used in Figs. 1a and 1b is courtesy of Japan's Ministry of Economy, Trade, and Industry (METI) and NASA. Credit: ANSMET.

found on firn are typically small in size, maybe not much larger than a centimeter or so in longest dimension and weighing less than 10 grams. ANSMET's policy is to collect all meteorites, no matter what the size, because we often cannot readily recognize small specimens of rare or interesting types in the field. On several occasions ANSMET teams have been pleasantly surprised to find out that a small, non-descript meteorite in the field actually turns out to be a lunar or martian specimen — good things do come in small packages!

Fig. 2. A lunar meteorite in a moraine at DW. The sample is ~4 centimeters in its longest dimension. Credit: ANSMET.

Furthermore, the downwind ice edge can be used to gauge whether or not a specific icefield contains a meteorite concentration: abundant small meteorites, probably a concentration upwind; few small meteorites, probably no concentration upwind.

Check Areas that have been Previously Searched

For icefields showing a meteorite concentration, ANSMET strives to systematically search all blue ice areas, relevant moraines, and ice edges in order to recover the most meteorites possible. On occasion we have time to revisit areas searched in previous seasons — and we almost always find more meteorites, sometimes a lot more meteorites. An extreme example of this is illustrated in Figs. 4a and 4b. Figure 4a shows an area known affectionately as The Beach, an amazingly meteorite-laden moraine at the foot of Mt. Ward on the eastern side of the icefields at DW. In 2014–2015, the ANSMET team recovered over 200 meteorites from the moraine, and you can see where most of them were found, as a flag marks each individual find. ANSMET returned to DW and The Beach in 2018–2019, and to our surprise, we found more than 100 additional meteorites (Fig. 4b)! Some of these meteorites seemed to be in almost the exact same location as meteorites found four years before. Most additional finds in previously searched areas (especially moraines) are undoubtedly due to human error; we simply missed them the first time around. Other additional finds are most likely the result of wind and/or glaciotectonic redistribution. Still others may be an actual recharge, where continuous ablation, over time, results in "new" meteorites being exposed at the ice surface. We're leaning toward glaciotectonic redistribution for the paradox of The Beach, but whatever the reason, it is worth having another look in areas where meteorites have been previously found.

Fig. 3. The downwind ice edge at DW with flags marking dozens of recovered meteorites that were fetched up on firn. Credit: ANSMET.

ANSMET is Important to the Planetary Science Community, and Vice Versa

The meteorites recovered by ANSMET are vitally important to planetary research. As such, the meteorites recovered by ANSMET are not owned by the principle investigators on the grant, nor by their universities where they are employed, but instead are expressly made available to researchers around the world for scientific study. Kevin Righter, the Antarctic Meteorite Curator at NASA Johnson Space Center (JSC), documents that since 1978 there have been over 3600 requests for samples, and over 1800 peer-reviewed journal articles published

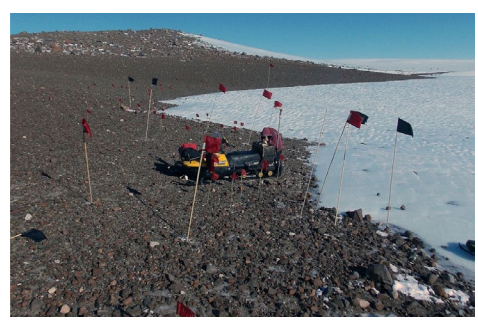

Fig. 4a. The Beach moraine at DW in 2014–2015, with longtime ANSMET mountaineer John Schutt collecting GPS data on an individual meteorite find. The plethora of flags (marking meteorite finds) attest to the moraine's unusually high meteorite concentration. Credit: ANSMET.

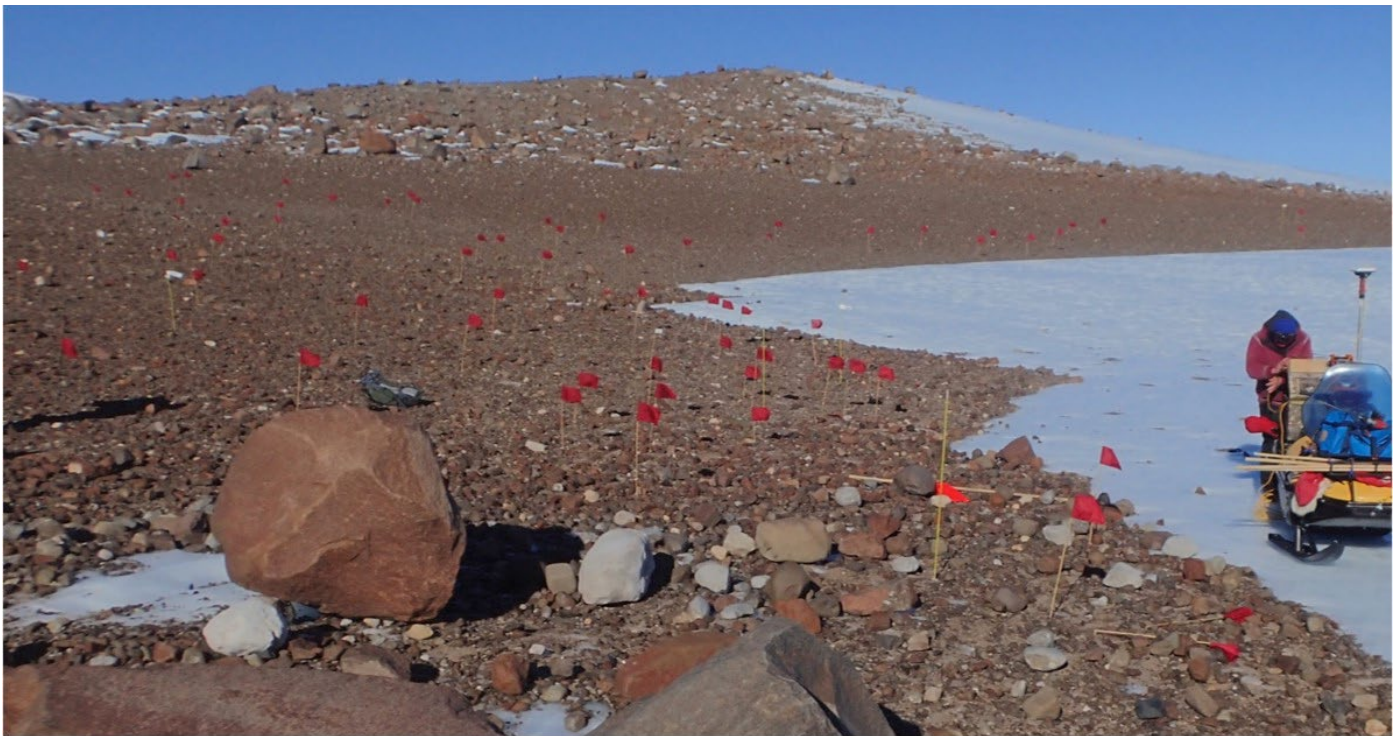

Fig. 4b. The Beach moraine at DW in the 2018–2019 season. Again, note the dozens and dozens of flags marking meteorite finds in the moraine, and compare their locations to those found in Fig. 4a. Credit: ANSMET.

using ANSMET meteorites as their major source of data. Current rates of publication predict about 60 peer-reviewed publications and nearly 200 abstracts per year on ANSMET meteorites. ANSMET meteorites are in particular demand because they are a continuous (yearly) supply of new extraterrestrial materials (except for this coming year; COVID has ruined everything fun). Furthermore, speedy initial characterization and classification by NASA JSC and the Smithsonian lead to rapid availability to researchers, and free of charge!

Finally, the planetary science community is vitally important to ANSMET. In a typical season ANSMET-funded personnel (principal investigators, mountaineers) rely on four to five volunteers to fill out the field team. These volunteers willingly give up two months of their time to live in tents in subzero temperatures and tirelessly search for extraterrestrial rocks on snowmobile and foot (with no showers for about six weeks). As of this past season, ANSMET has had ~195 (volunteer) participants on our field teams, and nearly three dozen of those volunteers have served on multiple ANSMET teams. In fact, ANSMET leadership receives approximately 100 letters per year from men and women around the globe who want to serve on an ANSMET team, and for that we are very grateful. Certainly the success and longevity of ANSMET would not be possible without the outstanding support of the planetary science community.

Suggested Readings

Harvey R. P. (2003) The origin and significance of Antarctic meteorites. Chem. Erde, 63, 93–147.

Righter K., Corrigan C., Harvey R., and McCoy T., eds. (2014) 35 Seasons of U.S. Antarctic Meteorites (1976–2010): A Pictorial Guide to the Collection. Special Publication Series, AGU/Wiley.

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FROM THE DESK OF LORI GLAZE

SMALL BODIES, BIG PLANS

Lori S. Glaze

Director, NASA's Planetary Science Division, October 2020

With the successful July 30 launch of our Mars 2020 mission, with the aptly named Perseverance rover and Ingenuity helicopter, our priorities in the Planetary Science Division (PSD) shift to the next major mission events on our calendar. First up, on October 20, will be the OSIRIS-REx touch-and-go (TAG) event. During TAG the spacecraft's Sample Acquisition Mechanism will be used to collect a sample of Bennu, which will eventually be returned to Earth. Since its arrival at the B-type carbonaceous asteroid in December 2018, OSIRIS-REx has been carefully and systematically surveying the asteroid's surface and characteristics. And over the course of this past spring and summer, the OSIRIS-REx team conducted two TAG rehearsals — the "Checkpoint" and "Matchpoint" rehearsals over the primary sampling site, Nightingale — when the spacecraft was flown down to approximately 75 m and 40 m above Bennu's surface, respectively.

Although the sample collection, and its ultimate return to Earth, will be the pinnacle of the OSIRIS-REx mission, the science results that continue to be produced by the mission team illustrate the fantastic insights we can gain from visiting the small bodies in our solar system and observing them from orbit or flybys. For example, we have recently seen a series of research articles published in JGR Planets and Nature Astronomy based on OSIRIS-REx results. In a planetary instance of giving and taking away, the team identified several pieces of another asteroid — likely Vesta — on Bennu's surface and witnessed regular particle ejection events, during which material was ejected from the asteroid's surface. Even more recently, in six papers published in Science and Science Advances, OSIRIS-REx scientists presented new findings on Bennu's surface material, geological characteristics, and dynamic history. So even before the precious pieces of Bennu are brought back to Earth for study in state-of-the-art laboratories, OSIRIS-REx is repeatedly revealing the dynamism of asteroids.

Of course, Bennu isn't the only small body we'll be visiting in the next few years. The next scheduled PSD launches will be the Double Asteroid Redirection Test (DART) and Lucy in July and October 2021, respectively, with Psyche following closely in 2022. Plus, New Horizons continues to explore the Kuiper belt after its fruitful flybys of Pluto and Arrokoth.

DART — the exciting first mission from the Planetary Defense Coordination Office — will use a kinetic impactor to demonstrate the asteroid deflection technique. The Didymos binary asteroid system (consisting of the larger Didymos and its smaller moonlet Dimorphos, with diameters of ~780 and 160 m, respectively) will be DART's target, with the spacecraft hitting Dimorphos with a nearly head-on impact in September 2022. The Light Italian Cubesat for Imaging of Asteroid (LICIACube), from the Italian Space Agency, will ride along with DART and will support the mission goals by capturing images of the impact effects on the surface and the expected ejecta plume it will generate. The relatively low energy of the impact will cause a change in the speed and path of Dimorphos rather than disrupt the integrity of the asteroid itself (there is no concern that the path of the system will intersect with that of Earth at any point).

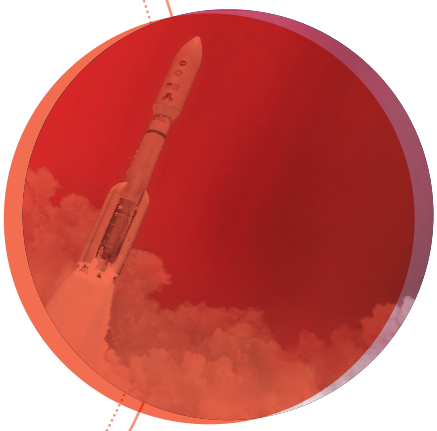
Earth-based telescopes, as part of an international observing campaign, will be used to determine the change in the orbit of Dimorphos after the impact.

Although the focus of DART will be the defense technology test (i.e., to help prevent future impacts of potentially hazardous asteroids to Earth), the mission will also play a larger role in an exciting international scientific collaboration known as the Asteroid Impact and Deflection Assessment (AIDA). As the second part of this collaboration, the European Space Agency's Hera mission will rendezvous with the Didymos system in 2026 (i.e., about four years after the DART impact) and will conduct a detailed survey of both bodies in the system. By measuring numerous properties of Dimorphos, including its mass, surface characteristics, porosity, and internal structure, as well as gaining a detailed look at the DART impact crater, the AIDA collaboration will provide unique science results. The combination of DART and Hera will revolutionize our current paradigms for understanding fundamental processes, including collision physics and cratering behaviors, as well as solar system formation in general.

Likewise, Lucy will provide a fantastic opportunity to gain new insights into planet formation processes — particularly for the outer solar system. The mission will make a tour of seven Trojan asteroids — asteroids trapped in Jupiter's orbit that are thought to be remnants of material that originally accreted to form the outer planets. The Lucy spacecraft will be equipped with four payload instruments to characterize the surface geology, surface color and composition, interior and bulk properties, as well as satellites and rings of each asteroid visited. Although searching for satellites is one of the mission goals, earlier this year the Lucy science team discovered — with the use of the Hubble Space Telescope (HST) — a satellite of one of the original asteroids slated for Lucy's tour. The satellite of Eurybates thus increased Lucy's total asteroid itinerary from seven to eight (including a main-belt asteroid as well), and the discovery of more satellites is definitely possible before Lucy arrives at Jupiter and begins its prime mission. The team is continuing to use HST to pin down the precise orbit of this new "moon."

Adding to the collection and variety of asteroid-types our upcoming missions will visit is Psyche — the mission and the asteroid. This Discovery mission will be the first time we send a spacecraft to explore a world that appears to be made of significantly more metal than other asteroids that are primarily made of rock, ice, or gas. Thought to be representative of the metallic — and inaccessible — cores of terrestrial planets, the asteroid Psyche provides us with the ability to study a key component of rocky planets and gain new understanding of planetary formation. The mission's payload of four instruments — a multispectral imager, a gamma-ray and neutron spectrometer, a magnetometer, and an X-band gravity science investigation — will be used to meet a set of science objectives, which will include determining if Psyche is indeed a protoplanet's core or if it is never-melted material, determining the relative ages of different regions on the asteroid's surface, and determining if the asteroid contains similar light elements than are thought to be present in the cores of terrestrial planets.

As the COVID pandemic continues, and as we round out the year of 2020, I gaze back at what our community was able to accomplish in the midst of a long string of unforeseen challenges. We truly persevered in every sense of the word. Thinking about these upcoming missions and bearing witness as they progress through their various development stages, however, is continuing to enthuse and engage me — and I hope you all as well. I know I speak for the whole planetary science community when I express my thanks to all the engineers, managers, and scientists for their hard work during these difficult times in non-ideal conditions. I am immensely grateful for their efforts in keeping these missions on track and on schedule. I hope you agree that these ongoing and upcoming missions to some of the smaller (and least known) bodies in our solar system are providing hope, excitement, and inspiration during these trying times. I'm thrilled to see the diversity of our planetary science portfolio, and I can't wait to see what solar system discoveries we uncover next.



LUNAR ISRU WORKSHOP 2019

The 2019 Lunar In Situ Resource Utilization (ISRU) Workshop — Developing a New Space Economy Through Lunar Resources and Their Utilization: A Stepped Approach to Establishing Cislunar Commerce Through Science and Exploration — was held at USRA HQ in Columbia, Maryland, on July 15–17, 2019. An international group of approximately 200 people from Europe, Australia, Canada, Korea, and Japan participated in this workshop, and represented government, commercial, and academic institutions.

The workshop brought together several broad communities not accustomed to working together: policy, legislation, law, and regulation; marketing, valuation, and finance; mineral exploration (characterization); mining (extraction); mineral processing; and planetary science. Each community has its own levels of history and terminology. A common observation among the workshop attendees was that moving forward would be faster and more effective with better communication. In addition to speeding information dispersal, better communication would help replace unknowing repetitions of effort with more nuanced, broadly based cooperative work. To that end, a glossary or dictionary focused on Space Resources should be developed in 2020 and maintained indefinitely in an easy-to-find location.

The workshop was set up to investigate the five phases of resource utilization: identification, characterization, extraction, processing, and markets. The first morning was devoted to introducing the workshop and community updates from space agencies and commercial entities. During the workshop, the attendees were polled on 14 questions and statements using Mentimeter to get a sense of where the majority opinion was regarding lunar ISRU. These questions were distributed throughout the sessions to encourage audience participation.

The major findings from this workshop included:

- Architectures for human spaceflight should be designed to utilize local resources.
- The most critical immediate issue for lunar ISRU is to execute a resource prospecting campaign to understand if the resources are actually geological reserves.
- Terrestrial mining companies will engage in lunar ISRU if they can see a net benefit to their operations.
- In order to get terrestrial mining companies involved, a market potential needs to be evident for products derived from space resources. A commitment to human permanence on the Moon and Mars is enabling for the commercial aspects of lunar ISRU and creation of markets.

At the end of the workshop, the audience was asked to respond to the question "What are the three takeaway messages you have learned at this workshop?" using one- or two-word answers. Ground truth, prospecting, collaboration, propellant, and simulants were the most popular answers.

More information about the workshop, including links to the program and abstracts, is available at the meeting website: www.hou.usra.edu/meetings/lunarisru2019/.

2020 ANNUAL MEETING OF PLANETARY GEOLOGIC MAPPERS

The 2020 Annual Meeting of Planetary Geologic Mappers was held virtually on July 23. Hosted by the Planetary Sciences Institute's Denver Office, the meeting attracted 95 investigators from around the U.S. and Europe.

As is always the case, this meeting provided an excellent opportunity for researchers to give an update of their NASA-funded mapping efforts. Every year, progress toward the publication of a U.S. Geological Survey (USGS) Science Investigation Map (SIM) is discussed, as well as scientific results derived from this mapping. In addition, because of the ease of attendance, there were several presentations from the U.K. and other parts of Europe. This provided much-needed collegial interaction between international colleagues in the discipline of planetary geologic mapping.

The meeting kicked off with several programmatic talks. These included a summary of the NASA-USGS Planetary Geologic Mapping Program. USGS reported that there are currently 245 planetary maps printed and posted by the Survey, of which 127 are available in GIS format. Forty-six maps are active and in progress, and six of those are in production. NASA is currently selecting approximately 4 new mapping projects per year, out of an average of 17 submitted. The USGS also presented a change to the technical review process, wherein a panel-style review will be conducted as opposed to the collation of two or three separate reviews. This should lead to more consistent reviews and hence more rapid publication of planetary maps once they are funded.

The standardization of methods for mapping impact craters throughout the solar system was also presented. As multiple small bodies (e.g., asteroids and comet nuclei) are now being imaged at high resolution, developing a consistent mapping approach to show impact craters is beneficial. Such methodologies will also become important as landing sites on the Moon and Mars are mapped at higher and higher spatial resolution.

In response to discussions at earlier Mappers' Meetings, we also heard about the plans to run the first Planetary Mappers Workshop in 2021. This workshop would provide an opportunity for newcomers to learn more of the techniques of planetary geologic mapping and would combine classroom-style activities with field mapping and hands-on GIS techniques.

As is the case with other NASA programs, the National Research Council's 2023–2033 Decadal Survey provides an opportunity for the planetary mapping community to address some of the perceived goals. A brief review of the current draft of the Planetary Mapping White Paper was presented, along with the request for input from the entire set of virtual attendees.

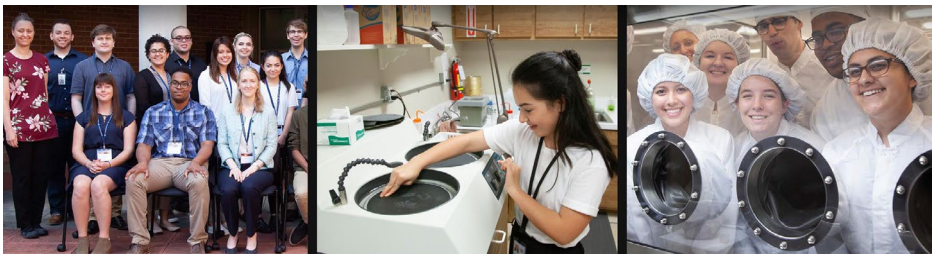
Multiple sessions were held to discuss the ongoing maps. These sessions included reports on maps of quadrangles on Mercury, Venus, the Moon, Mars, and outer solar system objects (Ceres and Triton). Global maps of Mercury, Europa, and Pluto were also presented, along with updates to some of the Apollo-era geologic maps of lunar landing sites. In addition to the funded maps heading to publication by the USGS, this meeting included many presentations from investigators working on less-formal maps. These include maps of the Mars 2020 (Perseverance Rover) landing site, as well as several efforts by European investigators to prepare for data collected by the BepiColombo mission now heading toward Mercury.

The hope is that this will be the only virtual Planetary Mappers' Meeting. The plan is to return to person-to-person discussions in June 2021 in Flagstaff, Arizona. While online discussions are better than none at all, attendees noted the lack of hallway discussions of mapping techniques and science results. Newcomers to this community also missed the opportunity to get detailed comments from more seasoned mappers, and we all missed the camaraderie of the after-hours social gatherings. However, the online chat capability of the meeting provided a reasonable substitute for quizzing the presenters. Several attendees noted a need for future online discussions regarding philosophical aspects of mapping techniques and methods, which would more consistently engage international colleagues. Such follow-on virtual discussions are now being considered. Needless to say, if travel restrictions are still in place, the success of this year's virtual meeting will be used as a model for a similar jamboree next year.

For more information about the meeting, including links to the program and abstracts, visit the meeting website at www.hou.usra.edu/meetings/pgm2020/.

OPPORTUNITIES FOR STUDENTS

LPI SUMMER INTERN PROGRAM IN PLANETARY SCIENCE



undergraduate students with an opportunity to perform cutting-edge, peer-reviewed research, learn from widely respected planetary scientists, and discover exciting careers in planetary science. During the 10-week internship, students have the opportunity to participate in enrichment activities, including NASA Johnson Space Center scientific visits, lectures, and career development workshops. Many of today's planetary science leaders got their start as LPI summer interns. Every career starts somewhere, and we encourage you to join us as you embark on your journey.

The Lunar and Planetary Institute invites undergraduates with at least 50 semester hours of credit to experience cutting-edge research in the lunar and planetary sciences. Students with majors in a physical or natural science, engineering, computer science, or mathematics have an advantage, but any eligible student may apply.

The 10-week program runs from June 7, 2021, to August 13, 2021. As a summer intern, you will work one-on-one with a scientist at the LPI or at the NASA Johnson Space Center on a research project of current interest in lunar and planetary science. Interns are selected by the project advisors who look for academic excellence and scientific interest and backgrounds compatible with their specific project needs.

Given the uncertainty resulting from the ongoing global pandemic, the 2021 summer internship program is expected to have a virtual component. Although we hope to provide some onsite internships, the need may arise to host fully virtual projects. Selected participants will be notified in March of the internship platform.

Benefits of an internship:

- Gain valuable research experience
- Develop new skills and refine others
- Meet and work with professionals, establishing contacts for letters of reference and networking
- Experience a new work environment

The LPI is located near the NASA Johnson Space Center, on the south side of Houston, Texas. On NASA's behalf, the LPI provides leadership in the scientific community for research in lunar, planetary, and solar system sciences, and linkage with related terrestrial programs. The deadline for applying for the 2021 program is November 23, 2020. For more information, including eligibility and selection criteria, areas of research, and an online application form, visit www.lpi.usra.edu/lpiintern/.

EXPLORATION SCIENCE SUMMER INTERN PROGRAM

TThe Lunar and Planetary Institute (LPI) is hosting a special summer intern program to involve students in activities that support missions to the Moon that utilize the Orion crew vehicle, the Deep Space Gateway, a crew lander, and other new assets that are being developed for missions beyond low-Earth orbit. A new program, called Artemis, is scheduled to land two astronauts near the lunar south pole in 2024,

followed by a series of crew landings that broaden our exploration of the lunar surface. This program will provide a unique opportunity to integrate scientific input with exploration activities in a way that mission architects and spacecraft engineers can use. Activities may involve assessments of landing sites and traverse

plans for multiple destinations that are responsive to NASA objectives. The LPI invites applications from graduate students in geology, planetary science, and related programs.

The Exploration Science Summer Intern Program builds on the success of the Lunar Exploration Summer Intern Program that was designed to evaluate possible landing sites on the Moon for robotic and human exploration missions. Over a five-year period (2008–2012), teams of students worked with LPI science staff and their collaborators to produce A Global Lunar Landing Site Study to Provide the Scientific Context for Exploration of the Moon. The program for 2021 is designed to have the same impact on future exploration activities. This will be a unique team activity that should foster extensive discussions among students and senior science team members.

The 10-week program runs from June 1, 2021, through August 6, 2021. Selected interns will receive a $6,300 stipend, and up to a $1,000 travel expense reimbursement for U.S. citizens, or up to $1,500 for foreign nationals.

We are currently planning to host the program in Houston. However, if the pandemic continues to restrict onsite activities, a virtual edition of the program will persevere.

The deadline for applying for the 2021 program is January 15, 2021. Selected candidates will be notified on March 15, 2021. For more information, including eligibility and selection criteria, areas of research, and an online application form, please visit www.lpi.usra.edu/exploration_intern/.

LPSC STUDENT OPPORTUNITIES

LPI Career Development Award

The Lunar and Planetary Institute (LPI) Career Development Award, which is open to both U.S. and non-U.S. applicants, will be given to selected graduate students who have submitted a first-author abstract for presentation at the 52nd Lunar and Planetary Science Conference.

The application deadline will be **January 6, 2021**.

Stephen E. Dwornik Student Awards

The deadline for Dwornik Award applications will be **January 6, 2021**.

The Dwornik Award was started in 1991 with a generous endowment by Dr. Stephen E. Dwornik, who wished to encourage U.S. students to become involved with NASA and planetary science. The Award consists of a plaque and a monetary award given for outstanding student presentations (in both poster and oral categories) or a plaque for honorable mentions (poster and oral) at the annual Lunar and Planetary Science Conference (LPSC). The awards are managed and judged by the Planetary Geology Division of the Geological Society of America.

The awards are open to students at any degree level in a field related to planetary geosciences who are either (1) U.S. citizens or non-citizens currently enrolled in a U.S. educational institution, or (2) are U.S. citizens currently enrolled in an international educational institution. Recent graduates, pre-college students, and postdoctoral fellows are not eligible. Students who have previously won a "best presentation" award as a graduate student are not eligible to compete again in either category. Students who have won a "best presentation" award as an undergraduate are not eligible to compete again in either category as an undergraduate but are eligible to compete in either category as a graduate student. Students who have won honorable mention award(s) as either a graduate or undergraduate student in either category are eligible to compete again.

For more details about either of these awards, visit www.hou.usra.edu/meetings/lpsc2021/student-awards/.

NASA'S SUMMER UNDERGRADUATE PROGRAM FOR PLANETARY RESEARCH (FORMERLY PGGRP)

The Summer Undergraduate Program for Planetary Research (SUPPR) is an eight-week summer internship providing undergraduates majoring in geology and related sciences with an opportunity to participate in NASA planetary geosciences research.

Students work under the direction of a NASA-sponsored planetary science investigator at various science institutions. The program is designed to help students gain educational experience in their fields of study while contributing to NASA missions and science.

College undergraduates who have not yet begun graduate studies and who are interested in learning about research in planetary geoscience are eligible. Previous participants of SUPPR (formerly PGGURP) are not eligible. Preference is given to U.S. citizens and permanent residents.

The online student and mentor application portal will accept applications through **February 12, 2021**. Notification of selection will be made by March 22, 2021. Successful applicants should be prepared to make a decision regarding the offer to participate within two days of notification. The program begins June 2021 and ends August 2021.

For more information, visit www.lpi.usra.edu/suppr/.

CALIFORNIA INSTITUTE OF TECHNOLOGY SUMMER UNDERGRADUATE RESEARCH FELLOWSHIPS

The Summer Undergraduate Research Fellowships (SURF) program is one of the "crown jewels" of Caltech. Since 1979, SURF students have had the opportunity to conduct research under the guidance of experienced mentors working at the frontier of their fields. Students experience the process of research as a creative intellectual activity from beginning (defining and developing a project) to end (presenting their results at SURF Seminar Day).

SURF is modeled on the grant-seeking process:

- Students collaborate with a potential mentor to define and develop a project
- Applicants write research proposals as

part of the application process
- Faculty review the proposals and recommend awards
- Students carry out the work over a 10-week period during the summer from June 15, 2021, through August 20, 2021
- At the conclusion of the program, students submit a technical paper and give an oral presentation at one of several SURF Seminar Days, symposia modeled on a professional technical meeting.

Application materials will be accepted through ***February 22, 2021****. For more information, visit www.sfp.caltech.edu/programs/surf.*

WAVE Fellows Program

Caltech's WAVE Fellows program aims to foster diversity by increasing the participation of underrepresented students in science and engineering Ph.D. programs and making Caltech's programs more visible and accessible to students not traditionally exposed to Caltech.

WAVE Fellows will have the opportunity to conduct research under the guidance of Caltech faculty working at the frontier of their fields.
- Applicants will identify several possible mentors with whom they are interested in working.
- Once accepted, Fellows will work with their mentor to define and develop a research project.
- Fellows will carry out the work over a 10-week period during the summer and submit two interim reports, a research abstract, and final paper. At the conclusion of the program, students give an oral presentation at one of several SURF Seminar Days, symposia modeled on a professional technical meeting

The application deadline for WAVE is ***January 8, 2021****. For more information, visit www.sfp.caltech.edu/programs/wavefellows.*

NASA INTERNSHIPS AND FELLOWSHIPS

NASA Internships are competitive awards to support educational opportunities that provide unique NASA-related research and operational experiences for high school, undergraduate, and graduate students, as well as educators. These opportunities serve students by integrating interns with career professionals emphasizing mentor-directed, degree-related tasks, while contributing to the operation of a NASA facility or the advancement of NASA's missions.

The application deadlines for the 2021 program are:
Spring Session: **November 6, 2020**
Summer Session: **March 5, 2021**
Fall Session: **July 9, 2021**

NASA Fellowships are competitive awards to support independently conceived or designed research, or senior design projects by highly qualified faculty, undergraduate, and graduate students, in disciplines needed to help advance NASA's missions, thus affording them the opportunity to directly contribute to advancements in STEM-related areas of study. Our Fellowship opportunities are focused on innovation, and generate measurable research results that contribute to NASA's current and future science and technology goals.

For more information, visit https://intern.nasa.gov/.

NASA POSTDOCTORAL PROGRAM

The NASA Postdoctoral Program (NPP) provides early-career and more senior scientists the opportunity to share in NASA's mission, to reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind.

NASA Postdoctoral Fellows work on 1- to 3-year assignments with NASA scientists and engineers at NASA centers and institutes to advance NASA's missions in Earth science, heliophysics, planetary science, astrophysics, space bioscience, aeronautics, engineering, human exploration and space operations, astrobiology, and science management.

NASA Postdoctoral Program Fellows contribute to our national scientific exploration,

confirm NASA's leadership in fundamental research, and complement the efforts of NASA's partners in the national science community.
Application cycle deadlines for the NASA Postdoctoral Program are **March 1, July 1, and November 1**, annually. Currently, the Astrobiology Program accepts applications only during the March and November rounds, and does not consider applications submitted during the July round. Note: You may submit only ONE application for ONE research opportunity per application cycle.

For more information, visit https://npp.usra.edu/.

SAO SUMMER INTERN PROGRAM

The Smithsonian Astrophysical Observatory (SAO) Summer Intern Program is a National Science Foundation (NSF) Research Experience for Undergraduates (REU) internship where students take on an astrophysics research project with an SAO or Harvard scientist. In 2021, the program will take place from Sunday, June 6, through Saturday, August 14. Students are expected to work at the Harvard-Smithsonian Center for Astrophysics for the full duration of the program. Interns are housed in Harvard's graduate student dormitory facilities.

The program is funded by NSF and the Smithsonian Institution.

Potential areas of research include (with a few example study subjects that reflect ongoing research at the Harvard Center for Astrophysics):

- Galaxies: How do they form, what powers them, how will they evolve over cosmic time?
- Our solar system: What are near-Earth asteroids? What kinds of objects populate the Oort cloud and Kuiper belt?
- Stars and planets: Are stellar models accurate? Where are new planets to be found?
- Lab astrophysics: What chemistry takes place in space? Do ices matter? How did the Earth get its water?
- Extreme astrophysics: What connects supermassive black holes to their host galaxies? What can we learn from X-ray emitting binary stars?

Undergraduate students interested in astronomy, astrophysics, physics, or related physical sciences are encouraged to apply. The application deadline for the Summer 2021 program is January 31, 2021. We can offer a wide range of projects to our interns. For more information, visit www.cfa.harvard.edu/opportunities/reu/.

INTERNSHIPS AT APL

Each summer, more than 400 college students from across the country are invited to intern at The Johns Hopkins University Applied Physics Laboratory (APL). As a college intern, you'll spend the summer contributing to engineering and research projects that help protect our nation and expand the frontiers of science.

APL College Summer Intern Program

APL offers science and engineering APL offers science and engineering internships each summer. The Laboratory's internship program provides practical work experience and an introduction to APL. Students spend the summer working with APL scientists and engineers, conducting research, developing leadership skills, and growing professionally. Applications are being accepted through March 31, 2021.

ATLAS Intern Program

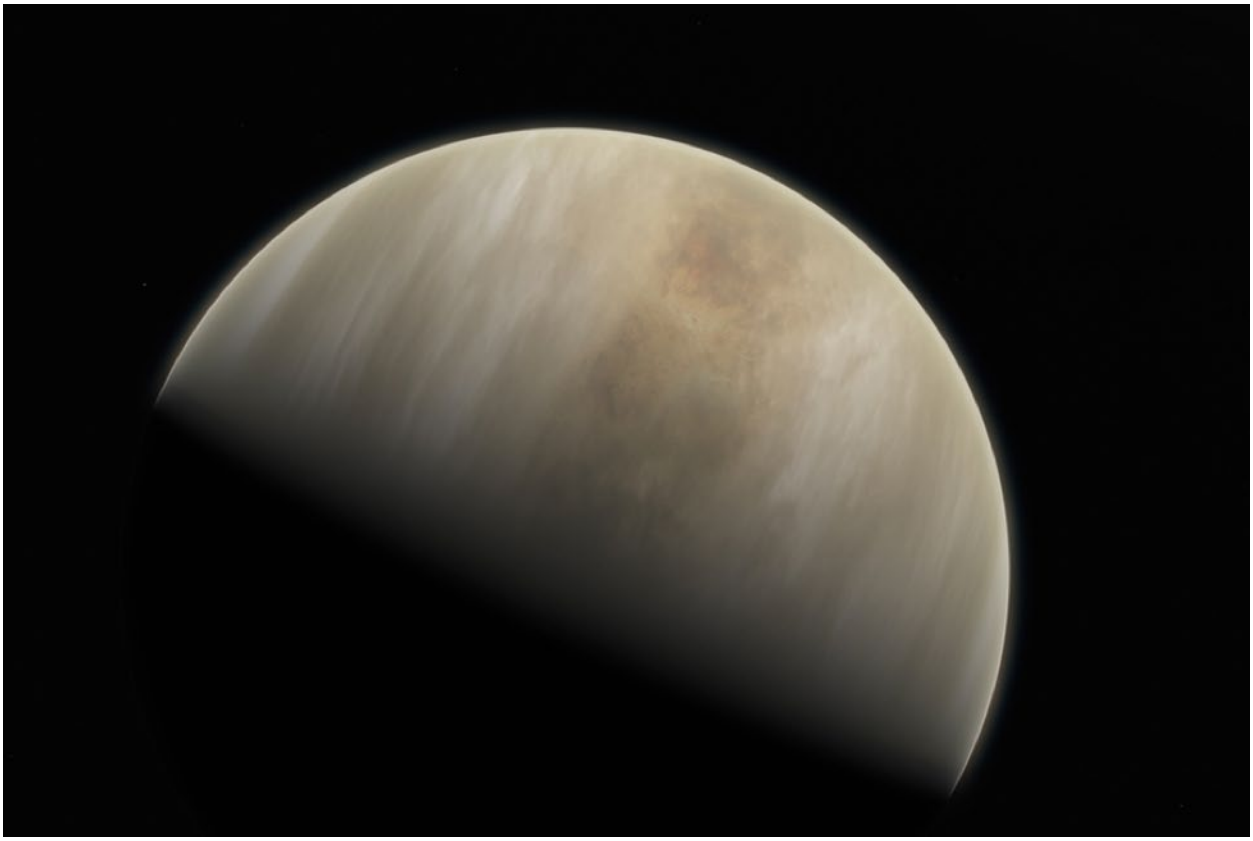
TThe APL Technology Leadership Scholars (ATLAS) program provides a unique educational opportunity for a select group of students from Historically Black Colleges and Universities, Hispanic-Serving Institutions, and Tribal Colleges and Universities. Applications are being accepted through March 31, 2021.

Discovery Program for College Graduates

The Discovery Program is an exciting opportunity for select recent college graduates. It consists of three to four assignments spanning multiple technical organizations across APL. The rotational assignments are six months in length each and are designed to provide participants with challenging work that will stimulate professional growth. Applications are accepted on a rolling basis.

For more information about these and other programs, visit www.jhuapl.edu/Careers/Internships.

ASTRONOMERS MAY HAVE FOUND A SIGNATURE OF LIFE ON VENUS



A phosphine detection in Venus' atmosphere may be a sign of life on the otherwise inhospitable planet.
Credit: ESO/M. Kornmesser/NASA/JPL/Caltech.

The search for life beyond Earth has largely revolved around our rocky red neighbor. NASA has launched multiple rovers over the years, with a new one currently en route, to sift through Mars' dusty surface for signs of water and other hints of habitability.

Now, in a surprising twist, scientists at the Massachusetts Institute of Technology (MIT), Cardiff University, and elsewhere have observed what may be signs of life in the clouds of our other, even closer planetary neighbor, Venus. While they have not found direct evidence of living organisms there, if their observation is indeed associated with life, it must be some sort of "aerial" life-form in Venus' clouds — the only habitable portion of what is otherwise a scorched and inhospitable world. Their discovery and analysis is published in the journal Nature Astronomy.

The astronomers, led by Jane Greaves of Cardiff University, detected in Venus' atmosphere a spectral fingerprint, or light-based signature, of phosphine. MIT scientists have previously shown that if this stinky, poisonous gas were ever detected on a rocky, terrestrial planet, it could only be produced by a living organism there. The researchers made the detection using the James Clerk Maxwell Telescope (JCMT) in Hawaii and the Atacama Large Millimeter Array (ALMA) observatory in Chile.

The MIT team followed up the new observation with an exhaustive analysis to see whether anything other than life could have produced phosphine in Venus' harsh, sulfuric environment. Based on the many scenarios they considered, the team concludes that there is no explanation for the phosphine detected in Venus' clouds, other than the presence of life.

"It's very hard to prove a negative," says Clara Sousa-Silva, research scientist in MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS). "Now, astronomers will think of all the ways to justify phosphine without life, and I welcome that. Please do, because we are at

the end of our possibilities to show abiotic processes that can make phosphine."

"This means either this is life, or it's some sort of physical or chemical process that we do not expect to happen on rocky planets," adds co-author and EAPS Research Scientist Janusz Petkowski.

Venus is often referred to as Earth's twin, as the neighboring planets are similar in their size, mass, and rocky composition. They also have significant atmospheres, although that is where their similarities end. Where Earth is a habitable world of temperate oceans and lakes, Venus' surface is a boiling hot landscape, with temperatures reaching 482°C (900°F) and a stifling air that is drier than the driest places on Earth.

Much of the planet's atmosphere is also quite inhospitable, suffused with thick clouds of sulfuric acid and cloud droplets that are billions of times more acidic than the most acidic environment on Earth. The atmosphere also lacks nutrients that exist in abundance on a planet surface. While Venus is clearly a challenging environment for any kind of life, there is a narrow, temperate band within Venus' atmosphere, between 48 and 60 kilometers (30 to 37 miles) above the surface, where temperatures range from –1° to 33°C (30° to 200°F). Scientists have speculated, with much controversy, that if life exists on Venus, this layer of the atmosphere, or cloud deck, is likely the only place where it would survive. And it just so happens that this cloud deck is where the team observed signals of phosphine.

"This phosphine signal is perfectly positioned where others have conjectured the area could be habitable," Petkowski says.

The detection was first made by Greaves and her team, who used the JCMT to zero in on Venus' atmosphere for patterns of light that could indicate the presence of unexpected molecules and possible signatures of life. When she picked up a pattern that indicated the presence of phosphine, she contacted Sousa-Silva, who has spent the bulk of her career characterizing the stinky, toxic molecule.

Sousa-Silva initially assumed that astronomers could search for phosphine as a biosignature on much farther-flung planets. "I was thinking really far, many parsecs away, and really not thinking literally the nearest planet to us."

The team followed up Greaves' initial observation using the more sensitive ALMA observatory, with the help of Anita Richards of the ALMA Regional Center at the University of Manchester. Those observations confirmed that what Greaves observed was indeed a pattern of light that matched what phosphine gas would emit within Venus' clouds.

The researchers then used a model of the venusian atmosphere, developed by Hideo Sagawa of Kyoto Sangyo University, to interpret the data. They found that phosphine on Venus is a minor gas, existing at a concentration of about 20 out of every billion molecules in the atmosphere. Although that concentration is low, the researchers point out that phosphine produced by life on Earth can be found at even lower concentrations in the atmosphere.

The MIT team, led by Bains and Petkowski, used computer models to explore all the possible chemical and physical pathways not associated with life that could produce phosphine in Venus' harsh environment. Bains considered various scenarios that could produce phosphine, such as sunlight, surface minerals, volcanic activity, a meteor strike, and lightning. Ranjan along with Paul Rimmer of Cambridge University then modeled how phosphine produced through these mechanisms could accumulate in the venusian clouds. In every scenario they considered, the phosphine produced would only amount to a tiny fraction of what the new observations suggest is present on Venus' clouds.

"We really went through all possible pathways that could produce phosphine on a rocky planet," Petkowski says. "If this is not life, then our understanding of rocky planets is severely lacking."

If there is indeed life in Venus' clouds, the researchers believe it to be an aerial form, existing only in Venus' temperate cloud deck, far above the boiling, volcanic surface.

"A long time ago, Venus is thought to have oceans, and was probably habitable like Earth," Sousa-Silva says. "As Venus became less hospitable, life would have had to adapt, and they could now be in this narrow envelope of the atmosphere where they can still survive. This could show that even a planet at the edge of the habitable zone could have an atmosphere with a local aerial habitable envelope."

Sousa-Silva is now leading an effort with Jason Dittman at MIT to further confirm the phosphine detection with other telescopes. They are also hoping to map the presence of the molecule across Venus' atmosphere, to see if there are daily or seasonal variations in the signal that would suggest activity associated with life.

"Technically, biomolecules have been found in Venus' atmosphere before, but these molecules are also associated with a thousand things other than life," Sousa-Silva says. "The reason phosphine is special is, without life it is very difficult to make phosphine on rocky planets. Earth has been the only terrestrial planet where we have found phosphine, because there is life here. Until now."

— Portions of this article were provided by Jennifer Chu and the MIT News Office

NASA's Mars 2020 Perseverance rover mission is on its way to the Red Planet to search for signs of ancient life and collect samples to send back to Earth.

Humanity's most sophisticated rover launched with the Ingenuity Mars Helicopter at 7:50 a.m. EDT (4:50 a.m. PDT) Friday on a United Launch Alliance (ULA) Atlas V rocket from Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida.

"With the launch of Perseverance, we begin another historic mission of exploration," said NASA Administrator Jim Bridenstine. "This amazing explorer's journey has already required the very best from all of us to get it to launch through these challenging times. Now we can look forward to its incredible science and to bringing samples of Mars home even as we advance human missions to the Red Planet. As a mission, as an agency, and as a country, we will persevere."

NASA LAUNCHES MARS 2020 PERSEVERANCE ROVER MISSION

An Atlas V rocket with NASA's Mars 2020 Perseverance rover onboard launches from Space Launch Complex 41, Thursday, July 30, 2020, at Cape Canaveral Air Force Station in Florida. The Perseverance rover is part of NASA's Mars Exploration Program, a long-term effort of robotic exploration of the Red Planet. Credit: NASA/Joel Kowsky.

The ULA Atlas V's Centaur upper stage initially placed the Mars 2020 spacecraft into a parking orbit around Earth. The engine fired for a second time and the spacecraft separated from the Centaur as expected. Navigation data indicate the spacecraft is perfectly on course to Mars.

Mars 2020 sent its first signal to ground controllers via NASA's Deep Space Network at 9:15 a.m. EDT (6:15 a.m. PDT). However, telemetry (more detailed spacecraft data) had not yet been acquired at that point. Around 11:30 a.m. EDT (8:30 a.m. PDT), a signal with telemetry was received from Mars 2020 by NASA ground stations. Data indicate the spacecraft had entered a state known as safe mode, likely because a part of the spacecraft was a little colder than expected while Mars 2020 was in Earth's shadow. All temperatures are now nominal and the spacecraft is out of Earth's shadow.

The Perseverance rover's astrobiology mission is to seek out signs of past microscopic life on Mars, explore the diverse geology of its landing site, Jezero Crater, and demonstrate key technologies that will help us prepare for future robotic and human exploration.

"Jezero Crater is the perfect place to search for signs of ancient life," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate at the agency's headquarters in Washington. "Perseverance is going to make discoveries that cause us to rethink our questions about what Mars was like and how we understand it today. As our instruments investigate rocks along an ancient lake bottom and select samples to return to Earth, we may very well be reaching back in time to get the information scientists need to say that life has existed elsewhere in the universe."

The martian rock and dust Perseverance's Sample Caching System collects could answer fundamental questions about the potential for life to exist beyond Earth. Two future missions currently under consideration by NASA, in collaboration with the European Space Agency (ESA), will work together to get the samples to an orbiter for return to Earth. When they arrive on Earth, the Mars samples will undergo indepth analysis by scientists around the world using equipment far too large to send to the Red Planet.

While most of Perseverance's seven instruments are geared toward learning more about the planet's geology and astrobiology, the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument's job is focused on missions yet to come. Designed to demonstrate that converting martian carbon dioxide into oxygen is possible, it could lead to future versions of MOXIE technology that become staples on Mars missions, providing oxygen for rocket fuel and breathable air.

Also future-leaning is the Ingenuity Mars Helicopter, which will remain attached to the belly of Perseverance for the flight to Mars and the first 60 or so days on the surface. A technology demonstrator, Ingenuity's goal is purely a flight test — it carries no science instruments.

Over 30 sols (31 Earth days), the helicopter will attempt up to five powered, controlled flights. The data acquired during these flight tests will help the next generation of Mars helicopters provide an aerial dimension to Mars explorations — potentially scouting for rovers and human crews, transporting small payloads, or investigating difficult-to-reach destinations.

The rover's technologies for entry, descent, and landing also will provide information to advance future human missions to Mars.

"Perseverance is the most capable rover in history because it is standing on the shoulders of our pioneers Sojourner, Spirit, Opportunity, and Curiosity," said Michael Watkins, director of NASA's Jet Propulsion Laboratory in Southern California. "In the same way, the descendants of Ingenuity and MOXIE will become valuable tools for future explorers to the Red Planet and beyond."

About seven cold, dark, unforgiving months of interplanetary space travel lay

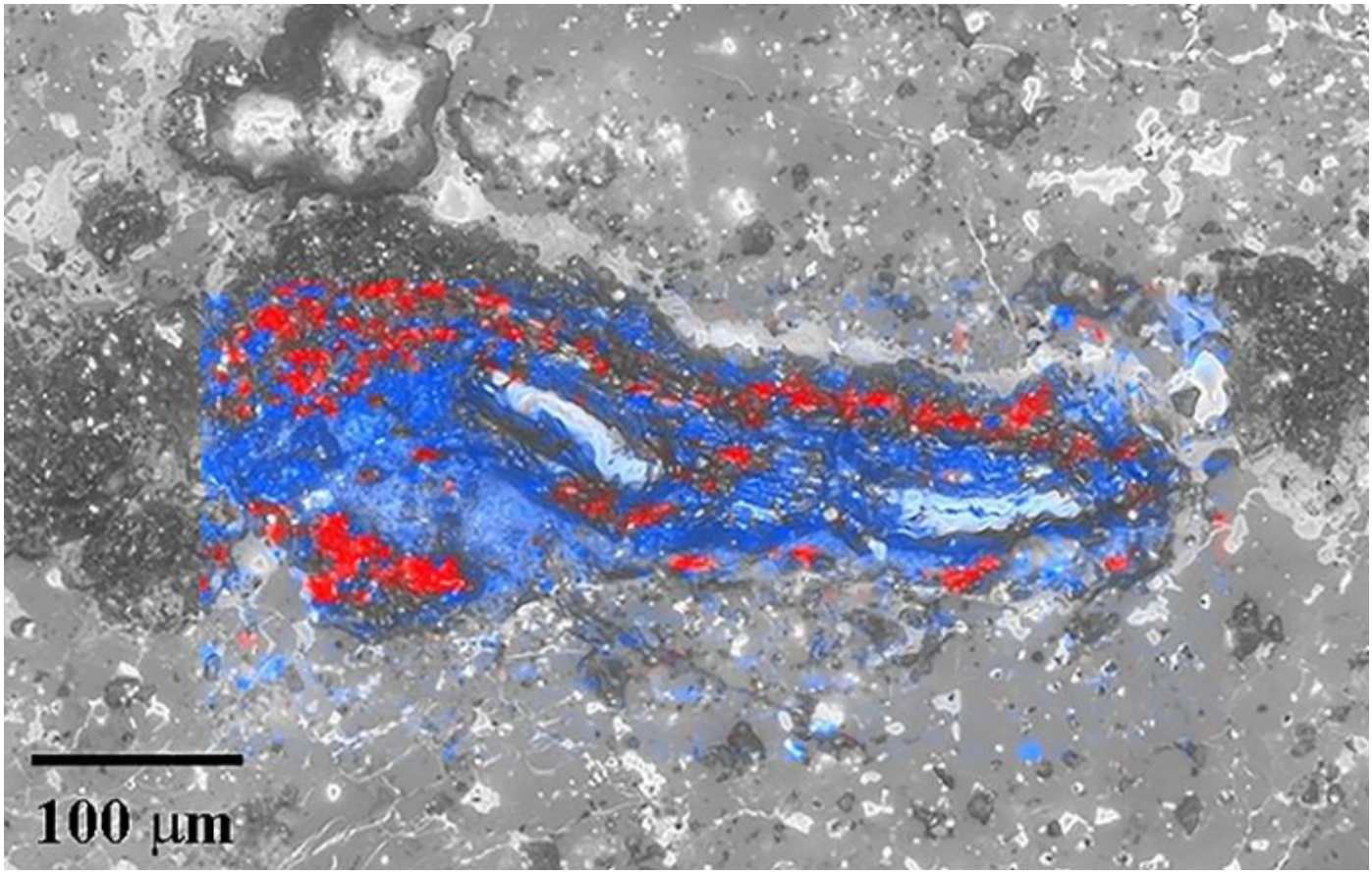
ahead for the mission — a fact never far from the mind of Mars 2020 project team.

"There is still a lot of road between us and Mars," said John McNamee, Mars 2020 project manager at JPL. "About 290 million miles of them. But if there was ever a team that could make it happen, it is this one. We are going to Jezero Crater. We will see you there February 18, 2021."

The Mars 2020 Perseverance mission is part of America's larger Moon to Mars exploration approach that includes missions to the Moon as a way to prepare for human exploration of the Red Planet. Charged with sending the first woman and next man to the Moon by 2024, NASA will establish a sustained human presence on and around the Moon by 2028 through NASA's Artemis program.

For more information about the Mars 2020 mission, visit mars.nasa.gov/marsv2020/.

NEW INSIGHTS INTO THE ORIGIN OF DIAMONDS IN METEORITES



Photomicrograph of a carbon area in the Northwest Africa 7983 ureilite meteorite. Reflected light image overlain with a false-color map from Raman spectroscopy showing distribution of diamond (red) and graphite (blue). Credit: Ryan Jakubek and Cyrena Goodrich.

Scientists have offered new insights into the origin of diamonds in ureilites (a group of stony meteorites). These diamonds most likely formed by rapid shock transformation from graphite (the common low-pressure form of pure carbon) during one or more major impacts into the ureilite parent asteroid in the early solar system.

Previously, researchers have proposed that diamonds in ureilites formed like those on Earth — deep in the mantle of the planet, where the high pressures needed to form diamond (a very dense, hard form of pure carbon) are created by the weight of overlying rock. If diamonds in ureilites formed this way, then the original parent body on which they formed must have been a large protoplanet — at least the size of Mars or Mercury.

However, new research conducted by Prof. Fabrizio Nestola (University of Padova, Italy), Dr. Cyrena Goodrich (Universities Space Research Association at the Lunar and Planetary Institute), and their colleagues show there is no evidence requiring formation under the high static pressures and long growth

time conditions of a planet's deep interior.

The team investigated diamonds in three ureilite samples using electron microscopy, micro X-ray diffraction, and Raman (laser) spectroscopy. Their investigations revealed both large (up to 100 micrometers in size) and small (nanometers in size) grains of diamond, along with metallic iron and graphite, in the carbon-rich regions located among the silicate mineral grains in these samples.

"We discovered the largest single-crystal diamond ever observed in a ureilite," says Dr. Cyrena Goodrich. "Importantly, the ureilites that we investigated have all been highly shocked, based on the evidence from their silicate minerals, which strongly suggests that both large and small diamonds in these rocks formed from original graphite via shock processes."

The origin of diamonds in ureilites has important implications for models of planetary formation in the early solar system. Present-day asteroids, from which most meteorites originate, are very small compared to the planets. However, planetary formation models predict that planets formed as a result of the accumulation of Moon- to Mars-sized planetary embryos (protoplanets). Advocates of the high static pressure hypothesis for the origin of ureilite diamonds argue that the ureilite parent body was one of these embryos. However, Nestola and co-authors demonstrate that the presence of diamonds in ureilites does not require a Mars-sized parent body.

"The origin of diamonds in ureilites has important implications for models of planetary formation in the early solar system."

Previously it was thought that micrometer-sized diamonds were too large to have formed in the short time periods (e.g., microseconds) during which peak pressures are maintained in impact events. However, Nestola et al. calculated that peak shock pressures could last for 4 to 5 seconds during a major impact such as that inferred for the ureilite parent body. This is sufficient for formation of 100-micrometer-sized diamonds when catalyzed by the presence of metal, a process commonly used in production of diamonds in industry. Since metal is ubiquitously associated with the carbon phases in ureilites, catalyzed formation of large diamonds from original graphite under shock compression is very likely.

Dr. Goodrich further notes, "Our findings are important because they not only indicate a shock origin for the diamonds in ureilites, as discussed by many previous researchers, they also refute arguments that have been made for the large-parent-body hypothesis. This type of scientific debate and testing of hypotheses is an essential part of making progress in science."

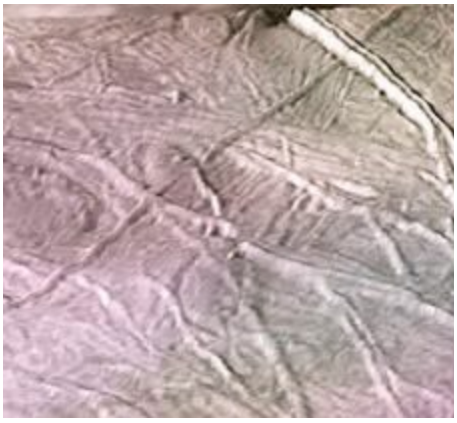
A 70-DEGREE SHIFT ON EUROPA WAS THE LAST EVENT TO FRACTURE ITS SURFACE

Europa's outer icy shell has completely reoriented itself in one of the last geologic events recorded on its young surface. Europa's poles are not where they used to be. Cracks in the surface of Jupiter's icy moon indicate its shell of ice rotated by 70° sometime in the last several million years. In addition to supporting prior evidence for the existence of a subsurface ocean, it also means that the geologic history of Europa's surface must be reexamined.

New research, led by Universities Space Research Association's Senior Staff Scientist Dr. Paul Schenk at the Lunar and Planetary Institute (LPI), confirms that Europa's large global-scale circular patterns formed during a large reorientation of the its icy outer shell with respect to its spin axis, a process known as true polar wander. This can only happen if the icy shell is uncoupled, or floating free, separated from the rocky core of the planet by a liquid water ocean. The findings were published July 29, 2020, in Geophysical Research Letters.

"Our key finding is that the fractures associated with true polar wander on Europa cross-cut all terrains. This means that the true polar wander event is very young and that the ice shell and all features formed on it have moved more than 70° of latitude from where they first formed," reports Schenk. "If true, then the entire recorded history of tectonics on Europa should be reevaluated."

Using a combination of global maps from Galileo and Voyager data with improved precision and detailed topographic data derived from them, a team



Photomicrograph of a carbon area in the Northwest Africa 7983 ureilite meteorite. Reflected light image overlain with a false-color map from Raman spectroscopy showing distribution of diamond (red) and graphite (blue). Credit: Ryan Jakubek and Cyrena Goodrich.

of scientists from the LPI in Houston, the University of California at Santa Cruz, and the University of Arizona in Tucson have correlated large fractures on the surface of Europa with previously identified concentric circular depressions on the surface.

NASA's Galileo spacecraft orbited Jupiter from 1995 to 2003 and returned hundreds of images of Europa's surface. Reconstruction of the global map of Europa at 200-meter resolution in color in preparation for a return to Europa revealed that these mysterious fracture systems were part of the circular true polar wander patterns identified previously. Topographic mapping in the highest-resolution images of the fractures at 40 meters per pixel show that the fractures are more than 200 meters deep. The fractures cut through all known terrains and thus show that the deformation related to the global reorientation (or true polar wander) event was one of the last events to occur on Europa. These features also imply that the floating ice shell on Europa may have thickened over time.

"Another important aspect of this work is that it makes predictions for additional features and ice shell properties which can be tested when the planned Europa Clipper spacecraft starts observing Europa," says coinvestigator Francis Nimmo at the University of California at Santa Cruz.

"In addition to generating global-scale tectonic features, true polar wander also produces global-scale gravity and shape perturbations, which affects gravity and shape constraints on the interior structure," says coinvestigator Isamu Matsuyama at the University of Arizona.

These too can be searched for and tested when Europa Clipper arrives later this decade. Europa Clipper will complete the map of Europa, including high-resolution images and soundings of these features. These maps will help determine the absolute age of these fractures and depressions and other consequences of the polar wander event that created them.

ASTRONOMERS DISCOVER AN EARTH-SIZED "PI PLANET" WITH A 3.14-DAY ORBIT

In a delightful alignment of astronomy and mathematics, scientists at the Massachusetts Institute of Technology (MIT) and elsewhere have discovered a "pi Earth" — an Earth-sized planet that zips around its star every 3.14 days, in an orbit reminiscent of the universal mathematics constant.

The researchers discovered signals of the planet in data taken in 2017 by the NASA Kepler Space Telescope's K2 mission. By zeroing in on the system earlier this year with SPECULOOS, a network of groundbased telescopes, the team confirmed that the signals were of a planet orbiting its star. And indeed, the planet appears to still be circling its star today, with a pi-like period, every 3.14 days.

"The planet moves like clockwork," says Prajwal Niraula, a graduate student in MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS), who is the lead author of a paper published in the Astronomical Journal, entitled "π Earth: A 3.14-day Earth-sized Planet from K2's Kitchen Served Warm by the SPECULOOS Team."

The new planet is labeled K2-315b; it's the 315th planetary system discovered within K2 data — just one system shy of an even more serendipitous place on the list.

The researchers estimate that K2-315b has a radius of 0.95 that of Earth's, making it just about Earth-sized. It orbits a cool, low-mass star that is about one-fifth the size of the Sun. The planet circles its star every 3.14 days, at a blistering 81 kilometers (181,000 miles) per second.

While its mass is yet to be determined, scientists suspect that K2-315b is terrestrial, like the Earth. But the pi planet is likely not habitable, as its tight orbit brings the planet close enough to its star to heat its surface up to 450 K (~350°F) — perfect, as it turns out, for baking actual pie.

"This would be too hot to be habitable in the common understanding of the phrase," says Niraula, who adds that

the excitement around this particular planet, aside from its associations with the mathematical constant pi, is that it may prove a promising candidate for studying the characteristics of its atmosphere.

"We now know we can mine and extract planets from archival data, and hopefully there will be no planets left behind, especially these really important ones that have a high impact," says co-author Julien de Wit, who is an assistant professor in EAPS, and a member of MIT's Kavli Institute for Astrophysics and Space Research.

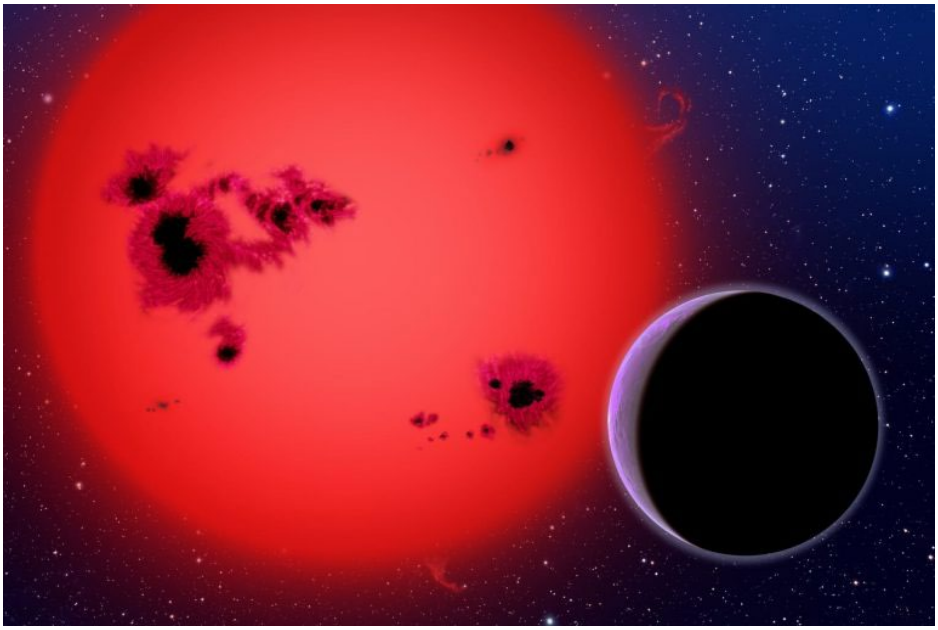
The researchers are members of SPECULOOS, an acronym for The Search for habitable Planets EClipsing ULtra-cOOl Stars, and named for a network of four 1-meter telescopes in Chile's Atacama Desert, which scan the sky across the southern hemisphere. Most recently, the network added a fifth telescope, which is the first to be located in the northern hemisphere, named Artemis — a project that was spearheaded by researchers at MIT.

The SPECULOOS telescopes are designed to search for Earth-like planets around nearby, ultracool dwarfs — small, dim stars that offer astronomers a better chance of spotting an orbiting planet and characterizing its atmosphere, as these stars lack the glare of much larger, brighter stars.

In particular, astronomers look at individual stars for signs of transits, or periodic dips in a star's light, that signal a possible planet crossing in front of the star, and briefly blocking its light.

Earlier this year, Niraula came upon a cool dwarf, slightly warmer than the commonly accepted threshold for an ultracool dwarf, in data collected by the K2 campaign — the Kepler Space Telescope's second observing mission, which monitored slivers of the sky as the spacecraft orbited around the Sun.

Over several months in 2017, the Kepler telescope observed a part of the sky that included the cool dwarf, labeled in the K2 data as EPIC 249631677. Niraula combed through this period and found around 20 dips in the light of this star that seemed to repeat every 3.14 days.



Artist's impression of an Earth-sized exoplanet orbiting an ultracool dwarf star. Credit: Harvard-Smithsonian Center for Astrophysics.

The team analyzed the signals, testing different potential astrophysical scenarios for their origin, and confirmed that the signals were likely of a transiting planet, and not a product of some other phenomena such as a binary system of two spiraling stars.

The researchers then planned to get a closer look at the star and its orbiting planet with SPECULOOS. But first, they had to identify a window of time when they would be sure to catch a transit.

"Nailing down the best night to follow up from the ground is a little bit tricky," says co-author Benjamin Rackham, who developed a forecasting algorithm to predict when a transit might next occur. "Even when you see this 3.14 day signal in the K2 data, there's an uncertainty to that, which adds up with every orbit."

With Rackham's forecasting algorithm, the group narrowed in on several nights in February 2020 during which they were likely to see the planet crossing in front of its star. They then pointed SPECULOOS' telescopes in the direction of the star and were able to see three clear transits: two with the network's Southern Hemisphere telescopes, and the third from Artemis, in the Northern Hemisphere.

The researchers say the new pi planet may be a promising candidate to follow up with the James Webb Space Telescope (JWST), to see details of the planet's atmosphere. For now, the team is looking through other datasets, such as from NASA's Transiting Exoplanet Survey Satellite (TESS) mission, and are also directly observing the skies with Artemis and the rest of the SPECULOOS network, for signs of Earth-like planets.

"There will be more interesting planets in the future, just in time for JWST, a telescope designed to probe the atmosphere of these alien worlds," says Niraula. "With better algorithms, hopefully one day, we can look for smaller planets, even as small as Mars."

— Portions of this article were provided by Jennifer Chu and the MIT News Office

VENUS MIGHT HAVE BEEN HABITABLE IF NOT FOR JUPITER

Venus may have once looked much like Earth, but has since lost its water. Its very circular orbit may be a clue as to why this happened. Credit: NASA Venus Through Time.

Venus might not be a sweltering, waterless hellscape today if Jupiter hadn't altered its orbit around the Sun, according to new University of California Riverside (UCR) research.

Jupiter has a mass that is two-and-a-half times that of all other planets in our solar system — combined. Because it is comparatively gigantic, it has the ability to disturb other planets' orbits.

Early in Jupiter's formation as a planet, it moved closer to and then away from the Sun due to interactions with the disk from which planets form as well as the other giant planets. This movement in turn affected Venus.

Observations of other planetary systems have shown that similar giant planet migrations soon after formation may be a relatively common occurrence. These are among the findings of a new study published in the Planetary Science Journal.

Scientists consider planets lacking liquid water to be incapable of hosting life as we know it. Although Venus may have lost some water early on for other reasons, and may have continued to do so anyway, UCR astrobiologist Stephen Kane said that Jupiter's movement likely triggered Venus onto a path toward its current, inhospitable state.

"One of the interesting things about the Venus of today is that its orbit is almost perfectly circular," said Kane, who led the study. "With this project, I wanted to explore whether the orbit has always been circular and if not, what are the implications of that?"

To answer these questions, Kane created a model that simulated the solar system, calculating the location of all the planets at any one time and how they pull one another in different directions.

Scientists measure how noncircular a planet's orbit is between 0, which is completely circular, and 1, which is not circular at all. The number between 0 and 1 is called the eccentricity of the orbit. An orbit with an eccentricity of 1 would not even complete an orbit around a star; it would simply launch into space, Kane said.

Currently, the orbit of Venus is measured at 0.006, which is the most circular of any planet in our solar system. However, Kane's model shows that when Jupiter was likely closer to the Sun about a billion years ago, Venus likely had an eccentricity of 0.3, and there is a much higher probability that it was habitable then.

"As Jupiter migrated, Venus would have gone through dramatic changes in climate, heating up then cooling off and increasingly losing its water into the atmosphere," Kane said.

Recently, scientists generated much excitement by discovering a gas in the clouds above Venus that may indicate the presence of life. The gas, phosphine, is typically produced by microbes, and Kane says it is possible that the gas represents "the last surviving species on a planet that went through a dramatic change in its environment."

For that to be the case, however, Kane notes the microbes would have had to sustain their presence in the sulfuric acid clouds above Venus for roughly a billion years since Venus last had surface liquid water — a difficult to imagine although not impossible scenario.

"One of the interesting things about the Venus of today is that its orbit is almost perfectly circular"

CHINA'S FARSIDE MOON EXPLORATION CONTINUES

China's Chang'e-4 lander and the well-wheeled rover have been switched to dormant mode within the Von Kármán crater in the South Pole-Aitken Basin on the farside of the Moon.

The farside mission landed on January 3, 2019.

According to the Lunar Exploration and Space Program Center of the China National Space Administration the lander and Yutu-2 rover have entered the 14-day lunar night cycle after working satisfactorily for a 22nd lunar day. As of February 20, the mobile robot has traveled over 547.17 meters (1795 feet).

Meanwhile, preparations are underway for the departure of Chang'e-5, the next mission in China's expanding lunar exploration initiative.

Yu Dengyun, deputy chief designer of China's lunar exploration program, said that Chang'e-5 will be launched by a Long March-5 heavy-lift booster from the Wenchang Space Launch Center in Hainan province by the end of 2020.

The 8.2-metric-ton robotic probe has four elements: an orbiter, lander, ascender, and reentry module. After the probe reaches lunar orbit, the components will separate into two parts, with the orbiter and reentry module remaining in orbit while the lander and ascender go down to the lunar surface. The lander and ascender will make a soft landing and then get to work on tasks such as using a drill to collect underground rocks and a mechanical arm to gather lunar soil.

After the surface operations are completed, the ascender's rocket will lift it to lunar orbit to dock with the reentry module. It will transfer lunar samples to the module, which then carries them back to Earth.

Considering these highly sophisticated operations, Chang'e-5 will be more difficult and challenging than previous Chinese lunar expeditions, Yu said, according to China media outlets.

"First of all, its most important task will be collecting lunar samples. The environment on the lunar surface, like the gravity there, is very different from that on Earth. So we must ensure that our technologies are functional and reliable during the collection and packing processes," Yu explained.

"The next challenge will be lifting the sample-carrying ascender from the Moon. All of our launches so far were made from Earth, but the coming launch will take place on lunar soil and use the Chang'e-5's lander as the launchpad. Consequently, the challenge will be whether our equipment can handle the complicated operation as it was designed to do."

After the capsule containing lunar collectibles is sent into orbit, it will approach the reentry module and dock with the latter, Yu said. "Previous rendezvous and docking by our spaceships occurred in low-Earth orbit, but this time it will take place in a lunar orbit," Yu said, adding that the last challenge will emerge during the Earth reentry process. The entry capsule will descend through Earth's atmosphere at a speed of 11.2 kilometers per second, much faster than previous reentry speeds of Chinese spacecraft.

If successful, the mission will make China the third nation to haul back to Earth lunar samples — following the former Soviet Union's robotic Moon program that ended in 1976, and the United States Apollo Moon landing program that concluded in 1972.

China has also made plans for Chang'e-6, 7, and 8 missions.

Chang'e-6 is expected to land at the Moon's south pole and carry back to Earth lunar regolith samples. Chang'e-7 is set to conduct a thorough investigation of the lunar south pole. Chang'e-8 will verify technologies that could be applied to future lunar expeditions, including a possible scientific outpost, according to the China National Space Administration.

— Portions of this article were provided by Leonard David

NASA MISSIONS SPY FIRST POSSIBLE "SURVIVOR" PLANET HUGGING WHITE DWARF STAR

An international team of astronomers using NASA's Transiting Exoplanet Survey Satellite (TESS) and retired Spitzer Space Telescope has reported what may be the first intact planet found closely orbiting a white dwarf, the dense leftover of a Sun-like star, only 40% larger than Earth.

The Jupiter-sized object, called WD 1856 b, is about seven times larger than the white dwarf, named WD 1856+534. It circles this

stellar cinder every 34 hours, more than 60 times faster than Mercury orbits our Sun.

"WD 1856 b somehow got very close to its white dwarf and managed to stay in one piece," said Andrew Vanderburg, an assistant professor of astronomy at the University of Wisconsin-Madison. "The white dwarf creation process destroys nearby planets, and anything that later gets too close is usually torn apart by the star's immense gravity. We still have many questions about how WD 1856 b arrived at its current location without meeting one of those fates."

A paper about the system, led by Vanderburg and including several NASA co-authors, appears in the September 17 issue of Nature and is now available online.

The TESS satellite spotted WD 1856 b about 80 light-years away in the northern constellation Draco. It orbits a cool, quiet white dwarf that is roughly 18,000 kilometers (11,000 miles) across, may be up to 10 billion years old, and is a distant member of a triple star system.

When a Sun-like star runs out of fuel, it swells up to hundreds to thousands of times its original size, forming a cooler red giant star. Eventually, it ejects its outer layers of gas, losing up to 80% of its mass. The remaining hot core becomes a white dwarf. Any nearby objects are typically engulfed and incinerated during this process, which in this system would have included WD 1856 b in its current orbit. Vanderburg and his colleagues estimate the possible planet must have originated at least 50 times farther away from its present location.

"We've known for a long time that after white dwarfs are born, distant small objects such as asteroids and comets can scatter inward towards these stars. They're usually pulled apart by a white dwarf's strong gravity and turn into a debris disk," said co-author Siyi Xu, an assistant astronomer at the international Gemini Observatory in Hilo, Hawaii, which is a program of the National Science Foundation's NOIRLab. "That's why I was so excited when Andrew told me about this system. We've seen hints that planets could scatter inward, too, but this appears to be the first time we've seen a planet that made the whole journey intact."

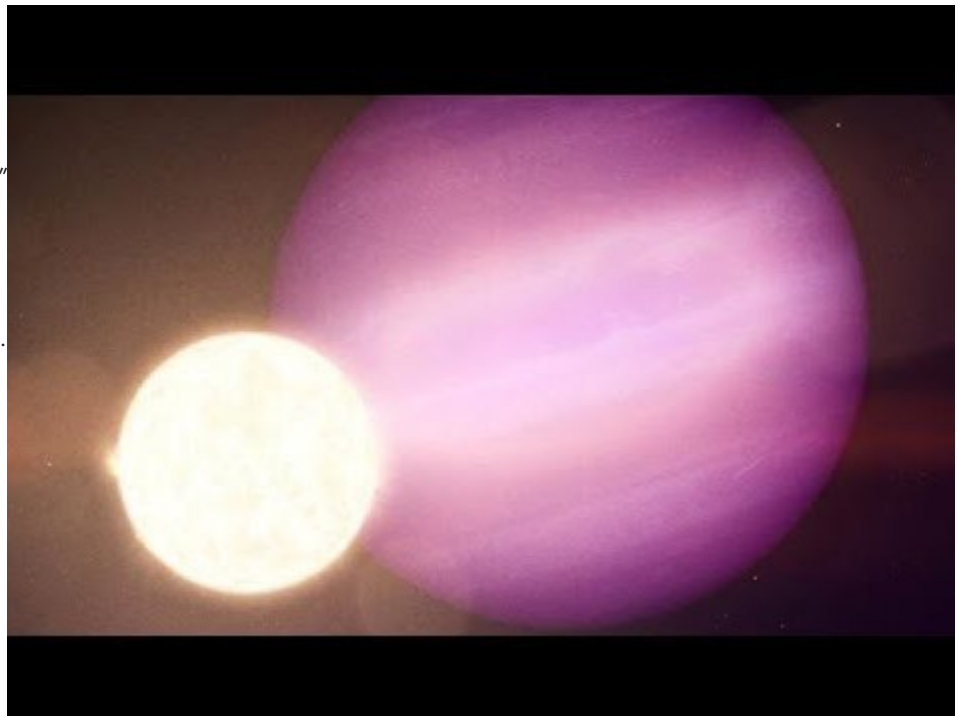
The team suggests several scenarios that could have nudged WD 1856 b onto an elliptical path around the white dwarf. This trajectory would have become more circular over time as the star's gravity stretched the object, creating enormous tides that dissipated its orbital energy.

"The most likely case involves several other Jupiter-size bodies close to WD 1856 b's original orbit," said co-author Juliette Becker, a 51 Pegasi b Fellow in planetary science at the California Institute of Technology (Caltech) in Pasadena. "The gravitational influence of objects that big could easily allow for the instability you'd need to knock a planet inward. But at this point, we still have more theories than data points."

Other possible scenarios involve the gradual gravitational tug of the two other stars in the system, red dwarfs G229-20 A and B, over billions of years, and a flyby from a rogue star perturbing the system. Vanderburg's team thinks these and other explanations are less likely because they require finely tuned conditions to achieve the same effects as the potential giant companion planets.

Jupiter-sized objects can occupy a huge range of masses, from planets only a few times more massive than Earth to low-mass stars thousands of times Earth's mass. Others are brown dwarfs, which straddle the line between planet and star. Usually scientists turn to radial velocity observations to measure an object's mass, which can hint at its composition and nature. This method works by studying how an orbiting object tugs on its star and alters the color of its light. But in this case, the white dwarf is so old that its light has become both too faint and too featureless for scientists to detect noticeable changes.

Instead, the team observed the system in the infrared using Spitzer, just a few months before the telescope was decommissioned. If WD 1856 b were a brown dwarf or low-mass star, it would emit its own infrared glow. This means Spitzer would record a brighter transit than it would if the object was a planet, which would block rather than emit light. When the researchers



Jupiter-sized WD 1856 b is nearly seven times larger than the white dwarf it orbits every day and a half. Astronomers discovered it using data from NASA's Transiting Exoplanet Survey Satellite (TESS) and now-retired Spitzer Space Telescope. Credit: NASA/JPL-Caltech/Goddard Space Flight Center.

> “Now we can explore many new intriguing possibilities for worlds orbiting these dead stellar cores”

compared the Spitzer data to visible light transit observations taken with the Gran Telescopio Canarias in Spain’s Canary Islands, they saw no discernable difference. That, combined with the age of the star and other information about the system, led them to conclude that WD 1856 b is most likely a planet no more than 14 times Jupiter’s size. Future research and observations may be able to confirm this conclusion.

Finding a possible world closely orbiting a white dwarf prompted co-author Lisa Kaltenegger, Vanderburg, and others to consider the implications for studying atmospheres of small rocky worlds in similar situations. For example, suppose that an Earth-sized planet were located within the range of orbital distances around WD 1856 where water could exist on its surface. Using simulated observations, the researchers show that NASA’s upcoming James Webb Space Telescope could detect water and carbon dioxide on the hypothetical world by observing just five transits.

The results of these calculations, led by Kaltenegger and Ryan MacDonald, both at Cornell University in Ithaca, New York, have been published in The Astrophysical Journal Letters and are available online.

“Even more impressively, Webb could detect gas combinations potentially indicating biological activity on such a world in as few as 25 transits,” said Kaltenegger, the director of Cornell’s Carl Sagan Institute. “WD 1856 b suggests planets may survive white dwarfs’ chaotic histories. In the right conditions, those worlds could maintain conditions favorable for life longer than the timescale predicted for Earth. Now we can explore many new intriguing possibilities for worlds orbiting these dead stellar cores.”

There is currently no evidence suggesting there are other worlds in the system, but it’s possible additional planets exist and haven’t been detected yet. They could have orbits that exceed the time TESS observes a sector or are tipped in a way such that transits don’t occur. The white dwarf is also so small that the possibility of catching transits from planets farther out in the system is very low.

IS THERE OTHER LIFE IN THE UNIVERSE? PURDUE SCIENTIST IS READY TO SEARCH FOR THE ANSWERS

Every rock on Mars is a time capsule for Briony Horgan, potentially holding information from billions of years ago that could help answer the questions about life in the universe today.

Horgan, an associate professor of planetary science at Purdue University, soon will have an opportunity to delve into those questions by searching for evidence of past microbial life as part of the NASA Mars rover Perseverance mission. Horgan’s research and a presentation led

Briony Horgan, associate professor of planetary science, stands in front of the VOSS Model on Purdue’s campus. Horgan is working to determine whether we are alone in the universe or if life once existed on other planets such as Mars. Credit: Purdue University/John Underwood.

NASA to select the rover landing site.

One of science's missing pieces of the puzzle is understanding how common simple life forms such as microbes are in the universe. Finding evidence of microbial life, even from billions of years ago, opens the door to new research.

"This is exciting because it is the first time we are really searching for ancient life in our solar system or beyond," Horgan said. "This is a chance to understand how rare or how common life like us is in the universe." The NASA rover Perseverance is expected to touch down on Mars in February. It is about a quarter of the way through its flight after launching on July 31.

To help the mission's odds of finding evidence of life, the Mars rover will land in Jezero Crater, just north of the planet's equator. Horgan was part of the science team that studied whether the site, which used to be a lake and large river delta, would be a good target for Perseverance.

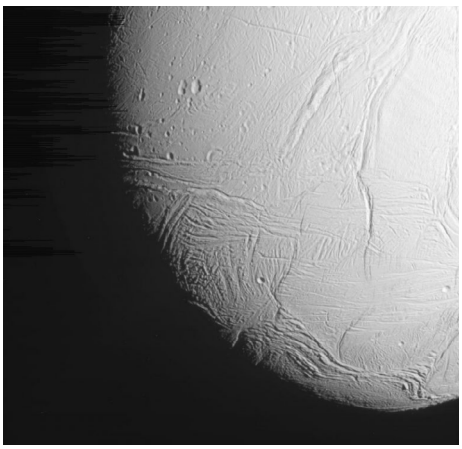
"It has everything we want in a landing site, not just ancient lake and mineral deposits, but it allows us also to get out of the crater and get out on the surrounding terrain to get at even older rocks that could tell us about the earliest parts of Mars history," Horgan said. "We're excited to see everything in and around the crater."

Almost 30 years of Mars research has led to this mission, and Horgan is excited about the location's possibilities. She has played a key role in the mission, including an important finding from mineralogy research she led on the location that contributed to Jezero Crater's selection and helping design the camera that will be the scientific eyes for Perseverance.

At this point, Earth is the only data source to help determine how and where life forms and evolves. But Horgan said erosion and plate tectonics have destroyed much of the evidence.

"But on Mars those rocks are just sitting on the surface waiting for us," she said. "If we show signs of ancient life on Mars, that is going to open up a whole new field of science trying to understand the origins of not just life on Mars but also on our own planet."

STUDY PINPOINTS PROCESS THAT MIGHT HAVE LED TO FIRST ORGANIC MOLECULES



This image of Saturn's icy, geologically active moon Enceladus was acquired by NASA's Cassini spacecraft during its October 2015 flyby. Enceladus hides a global ocean of liquid salty water beneath its crust and might also have hydrothermal vents not unlike the hydrothermal vents that dot the ocean floor here on Earth. Credit: NASA/JPL-Caltech/Space Science Institute.

New research led by the American Museum of Natural History and funded by NASA identifies a process that might have been key in producing the first organic molecules on Earth about 4 billion years ago, before the origin of life. The process, which is similar to what might have occurred in some ancient underwater hydrothermal vents, may also have relevance to the search for life elsewhere in the universe. Details of the study are published in the journal Proceedings of the National Academy of Sciences.

All life on Earth is built of organic molecules — compounds made of carbon atoms bound to atoms of other elements such as hydrogen, nitrogen, and oxygen. In modern life, most of these organic molecules originate from the reduction of carbon dioxide (CO_2) through several "carbon-fixation" pathways (such as photosynthesis in plants). But most of these pathways either require energy from the cell in order to work, or were thought to have evolved relatively late. So how did the first organic molecules arise, before the origin of life?

To tackle this question, Museum Gerstner Scholar Victor Sojo and Reuben Hudson from the College of the Atlantic in Maine devised a novel setup based on microfluidic reactors, tiny self-contained laboratories that allow scientists to study the behavior of fluids — and in this case, gases as well — on the microscale. Previous versions of the reactor attempted to mix bubbles of hydrogen gas and CO_2 in liquid but no reduction occurred, possibly because the highly volatile hydrogen gas escaped before it had a chance to react. The solution came in discussions between Sojo and Hudson, who shared a lab bench at the RIKEN Center for Sustainable Resource Science in Saitama, Japan. The final reactor was built in Hudson's laboratory in Maine.

"Instead of bubbling the gases within the fluids before the reaction, the main innovation of the new reactor is that the fluids are driven by the gases themselves, so there is very little chance for them to escape," Hudson said. The researchers used their design to combine hydrogen with CO_2 to produce an organic molecule called formic acid ($HCOOH$). This synthetic process resembles the only known CO_2-fixation pathway that does not require a supply of energy overall, called the Wood-Ljungdahl acetyl-CoA pathway. In turn, this process resembles

reactions that might have taken place in ancient oceanic hydrothermal vents.

"The consequences extend far beyond our own biosphere," Sojo said. "Similar hydrothermal systems might exist today elsewhere in the solar system, most noticeably in Enceladus and Europa — moons of Saturn and Jupiter, respectively — and so predictably in other water-rocky worlds throughout the universe."

"Understanding how carbon dioxide can be reduced under mild geological conditions is important for evaluating the possibility of an origin of life on other worlds, which feeds into understanding how common or rare life may be in the universe," added Laurie Barge from NASA's Jet Propulsion Laboratory, an author on the study.

The researchers turned CO2 into organic molecules using relatively mild conditions, which means the findings may also have relevance for environmental chemistry. In the face of the ongoing climate crisis, there is an ongoing search for new methods of CO2 reduction.

"The results of this paper touch on multiple themes: from understanding the origins of metabolism, to the geochemistry that underpins the hydrogen and carbon cycles on Earth, and also to green chemistry applications, where the bio-geo-inspired work can help promote chemical reactions under mild conditions," added Shawn E. McGlynn, also an author of the study, based at the Tokyo Institute of Technology.

SURPRISING NUMBER OF EXOPLANETS COULD HOST LIFE

Our solar system has one habitable planet — Earth. A new study shows other stars could have as many as seven Earth-like planets in the absence of a gas giant like Jupiter.

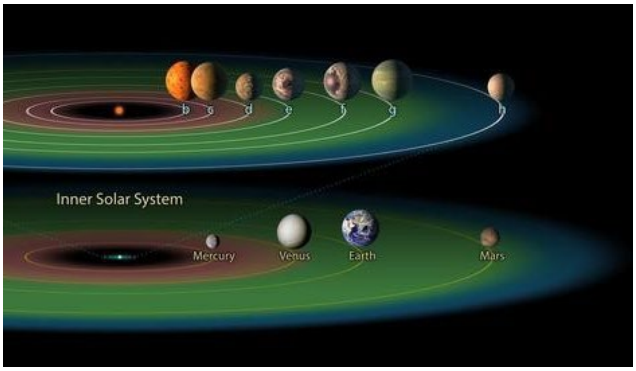
This is the conclusion of a study led by University of California Riverside (UCR) astrobiologist Stephen Kane published in the Astronomical Journal. The search for life in outer space is typically focused on what scientists call the "habitable zone," which is the area around a star in which an orbiting planet could have liquid water oceans — a condition for life as we know it.

Kane had been studying a nearby solar system called Trappist-1, which has three Earth-like planets in its habitable zone. "This made me wonder about the maximum number of habitable planets it's possible for a star to have, and why our star only has one," Kane said. "It didn't seem fair!"

His team created a model system in which they simulated planets of various sizes orbiting their stars. An algorithm accounted for gravitational forces and helped test how the planets interacted with each other over millions of years.

They found it is possible for some stars to support as many as seven, and that a star like our Sun could potentially support six planets with liquid water. "More than seven, and the planets become too close to each other and destabilize each other's orbits," Kane said.

Why then does our solar system only have one habitable planet if it is capable of supporting six? It helps if the planets' movement is circular rather than oval or irregular, minimizing any close contact and maintaining stable orbits.



The Trappist-1 planetary system has three planets in its habitable zone, compared to our solar system, which has only one. Credit: NASA/JPL/Caltech.

Kane also suspects Jupiter, which has a mass two-and-a-half times that of all the other planets in the solar system combined, limited our system's habitability. "It has a big effect on the habitability of our solar system because it's massive and disturbs other orbits," Kane said.

Only a handful of stars are known to have multiple planets in their habitable zones. Moving forward, Kane plans to search for additional stars surrounded entirely by smaller planets. These stars will be prime targets for direct imaging with NASA telescopes like the one at Jet Propulsion Laboratory's Habitable Exoplanet Observatory.

Kane's study identified one such star, Beta CVn, which is relatively close by at 27 light-years away. Because it doesn't have a Jupiter-like planet, it will be included as one of the stars checked for multiple habitable zone planets. Future studies will also involve the creation of new models that examine the atmospheric chemistry of habitable zone planets in other star systems.

Projects like these offer more than new avenues in the search for life in outer space. They also offer scientists insight into forces that might change life on our own planet one day.

"Although we know Earth has been habitable for most of its history, many questions remain regarding how these favorable conditions evolved with time, and the specific drivers behind those changes," Kane said. "By measuring the properties of exoplanets whose evolutionary pathways may be similar to our own, we gain a preview into the past and future of this planet — and what we must do to maintain its habitability."

VIRTUAL EDUCATION AND PUBLIC ENGAGEMENT OPPORTUNITIES

Organizations across the country are curtailing education and public engagement programs. Some are conducting online programs; contact your local museums and planetariums, libraries, Solar System Ambassadors, or amateur astronomy clubs to determine how you can participate.

Upcoming Opportunities for Engaging Public Audiences

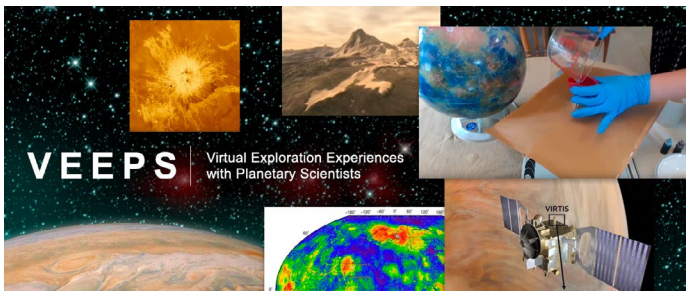
- October 20 — OSIRIS-REx sample collection from asteroid Bennu; discuss asteroids and meteorites
- October 31 — Full/Blue Moon; discuss current and future lunar exploration plans
- December 22 — Rare conjunction of Jupiter and Saturn; view Jupiter and Saturn through telescopes and discuss insights from the Juno mission and plans for Europa Clipper and Dragonfly

A variety of education and public engagement resources are available for use with audiences:

NASA at Home

The NASA at Home website has e-Books, videos, virtual tours, and more.

NASA SMD Resources for Learners has a variety of resources provided by NASA's Science Mission Directorate.



LPI's Virtual Exploration Experiences with Planetary Scientists (VEEPS) program provides an opportunity for families to connect with planetary scientists from home! Each 30-minute online session includes a scientist presentation, a demonstration related to the topic, and some time for questions and discussion with the scientist.

LPI's Cosmic Explorations Speaker Series Archive

provides an archive of past presentations in this series on the LPI YouTube channel.

LPI's Explore! Resources provide Explore! activities to engage children and pre-teens in the wonders of lunar exploration; the planets Earth, Jupiter, and Mars; rockets; staying healthy in space; and more!

To view Explore! how-to-videos, visit https://bit.ly/3eeljlz.

RESOURCES FOR PLANETARY SCIENTISTS INVOLVED IN PUBLIC ENGAGEMENT

The Lunar and Planetary Institute's (LPI's) education and public engagement team is pleased to assist planetary scientists in their communication and public engagement activities. The LPI conducts scientist workshops to provide insight on meeting audience needs and has placed a variety of recommendations online. For more information, visit www.lpi.usra.edu/education/scientist-engagement.

IN MEMORIAM

Nadine G. Barlow. Credit: University of Arizona.

NADINE G. BARLOW

1958–2020

Nadine Gail Barlow passed away on August 17, 2020, after a two-year battle with cancer.

A native of San Marcos, California, she was an alumna of the University of Arizona, where she received her Bachelor of Science and Doctoral degrees. After postdoctoral appointments at the Lunar and Planetary Institute and NASA's Johnson Space Center in Houston, Texas, and a professorship at the University of Central Florida in Orlando, Florida (where she was recognized with the 2002 University Excellence in Undergraduate Teaching Award), Barlow came to Flagstaff in 2002 to the (then) Department of Physics and Astronomy at Northern Arizona University (NAU).

In her 18 years at NAU, she ascended the academic ranks, eventually becoming Department Chair of Astronomy and Planetary Science. Barlow was the recipient of numerous awards for teaching excellence. Largely responsible for doubling the size of the department, she grew its curriculum into a Ph.D.-granting program. Barlow supervised many students over the years, both undergraduate and graduate, and was a popular mentor and friend to those under her tutelage.

She served on the boards and committees of many professional societies throughout her career, and published numerous papers in the scientific literature. Academic outreach was a priority, bringing the Arizona Space Grant Program to NAU, and fostering cooperation between NAU, Lowell Observatory, and the U.S. Geological Survey. Right up until two weeks before her passing, she organized scientific meetings and consortia, bringing together scientists from around the world to discuss and collaborate on their findings.

Academically, Barlow specialized in impact cratering processes, particularly on the planet Mars. For her Ph.D. dissertation — almost on a dare — she mapped, measured, and classified every crater on the entire planet larger than 8 kilometers (5 miles) in diameter. These data were used to establish the detailed relative chronology (relative age) of martian geologic features. Throughout her career, she maintained and expanded this database, as later spacecraft missions returned increasingly detailed images of the planet. Her academic interests spanned impact cratering on planets and satellites throughout the solar system, from Mercury to Pluto. Her curiosity about cratering processes increased along with the reach of our satellite explorations. Asteroid 15466 Barlow is named in her honor by the International Astronomical Union.

A prize for Undergraduate Research Excellence is being established at NAU's Department of Astronomy and Planetary Sciences in her name.

H. JAY MELOSH

1947–2020

Nadine G H. Jay Melosh. Credit: Purdue University.. Barlow. Credit: University of Arizona.

H. Jay Melosh, a Distinguished Professor of Earth and Atmospheric Sciences at Purdue University, passed away on September 11, 2020.

Melosh earned a degree in physics from Princeton University and a doctoral degree in physics and geology from the California Institute of Technology in 1972. His Ph.D. thesis concerned quarks, but his professional research interests included impact craters, planetary tectonics, and the physics of earthquakes and landslides. His recent research included studies of the giant impact origin of the Moon, the Chicxulub impact that is thought to have extinguished most dinosaurs, and studies of ejection of rocks from their parent bodies. He was also active in astrobiological studies that relate chiefly to the exchange of microorganisms between the terrestrial planets (a process known as panspermia or transpermia).

Melosh joined the faculty of Purdue University in 2009 and remained on staff there until his death. Prior to his job at Purdue, he was a Professor of Planetary Science at the University of Arizona from 1982–2009.

Melosh was a member of the American Geophysical Union, Geological Society of America, Meteoritical Society, American Astronomical Society (Division of Planetary Sciences,) and the American Association for the Advancement of Science. He was the recipient of the Barringer Medal of the Meteoritical Society for his work on the physics of impact, and of the G. K. Gilbert Award from the Geological Society of America. He was elected to the National Academy of Sciences in 2003.

Asteroid 8216 Melosh is named in his honor.

Brian J. O'Brien. Credit: University of Western Australia.

BRIAN J. O'BRIEN

1934–2020

Dr. Brian J. O'Brien, a space scientist whose career spanned the entire history of space exploration, died in Australia on August 7, 2020, at the age of 86. His space instruments were carried on spacecraft ranging from the original Explorer missions to the lunar landings and his scientific contributions covered a period of more than 60 years.

O'Brien graduated in Physics from the University of Sydney in 1954 and received his Ph.D. in Physics there in 1957. The dawning of the space program in the late 1950s captured his curiosity, and he moved to the University of Iowa to work with Professor James Van Allen on the early Explorer satellites as an Assistant then Associate Professor. This experience honed his skills in spacecraft technology and his interests moved to the study of lower-energy particles, shifting from the megaelectron-volt energies of the early Geiger counters on the Explorers to the kiloelectron-volt energies of the precipitating particles that caused the aurora.

The growth of interest in space exploration led to the creation of the Space Science department at Rice University, and O'Brien became a Professor in the new department beginning in 1963. His expertise in instruments and satellites led to multiple missions ranging from the Twins sounding rockets from Fort Churchill to the Aurora 1 satellite. His creativity, motivation, and persistence were passed on to his students, for whom he was an outstanding teacher and mentor.

With President Kennedy's commitment of the nation to sending astronauts to the Moon, O'Brien broadened his space interests to exploring the more distant reaches of the Earth's magnetosphere in the geotail by pursuing the possibility of placing particle instruments on the surface of the Moon on the Apollo Lunar Surface Experiments Package (ALSEP) mission. His success in this pursuit is illustrated by an occurrence leading up to the selection. NASA planned a pre-proposal conference at the Manned Spacecraft Center to solicit ideas for the scientific payload. Multiple scientists gathered in the room to talk about their ideas and concepts for the ALSEP package, showing charts and sketches. When it became O'Brien's turn to speak, he reached down into his briefcase at his feet and pulled out an ion/electron instrument that had already flown successfully on his sounding rockets and Aurora 1 satellite and said, "I'd like to fly this to the Moon!" It was selected by NASA and flew on three missions to the Moon.

As the plans and technology were developing in the 1960s for the Apollo missions, a concern was raised about the dust on the surface of the Moon and whether it was so deep that the landing spacecraft would sink into the surface. There was evidence on both sides of the issue. In talking with Buzz Aldrin, O'Brien became interested in trying to measure the amount of the pervasive dust because it could affect the operation of the instruments on the lunar surface and might compromise the safe operation of many of the technical systems including the astronaut's equipment and the interior of the lunar lander and from it to the Command Module with which the lander would later dock after the landing. The ALSEP package had already been accepted and was being built. On a plane flight home after one of the ALSEP investigator meetings, O'Brien had an idea about how to easily measure the amount of floating dust that could be created by the astronauts activities and by the launch of the upper portion of the Lunar Excursion Module rocket when it took the astronauts back up to the orbiting Command Module. His idea was to have a small solar cell mounted on the side of one of the instruments on the ALSEP and to measure the change in the solar cell current caused by the amount of dust that was floating around during different lunar conditions. NASA resisted this late addition to the payload, but finally agreed. The Lunar Dust Detectors were built and flown on Apollos 11, 12, 13, and 14. The knowledge of the lunar environment that came from these detectors has been used continuously, and O'Brien's papers on this subject are still important. These results were most recently used by the Chinese space program in designing their lunar rover, which is on the backside of the Moon, and will doubtlessly be used in the design of the new spacecraft that will take astronauts to the lunar surface as part of the Artemis program in the coming decade. He most recently gave a talk at the Workshop on Lunar Dust and Its Impact on Human Exploration at the Lunar and Planetary Institute on February 10, 2020, at the age of 86.

O'Brien returned to Australia in 1968 and became the Director of the Environmental Protection Authority for Western Australia and an Adjunct Professor at the University of Western Australia. He has published more than 400 papers. He received the NASA Medal for Exceptional Scientific Achievement and was elected a Fellow of the Australian Academy of Technological Sciences and Engineering.

O'Brien was a quintessential scientist and explorer. His curiosity, intellect, clever creativity, and indefatigable persistence and optimism created an exciting life and an enduring legacy for his science and for those of us who had the privilege of having our careers shaped by his foresight and enthusiasm. He will be missed, but the knowledge that he has left us will last forever.

— Text courtesy of Rick Chappell, Jim Burch, Patricia Reiff and Jackie Reasoner

John T. Wasson. Credit: UCLA.

JOHN T. WASSON

1934–2020

John T. Wasson, a world-renowned expert in meteorites and lunar rocks who had a mineral named after him, died at home in Los Angeles on September 8. He was 86.

The professor emeritus of the Department of Earth, Planetary and Space Sciences at the University of California Los Angeles (UCLA) helped devise modern chemical classifications for the space debris that can fall to Earth as brief fireballs or "bolides" big enough to create an impact crater. Wasson joined the UCLA faculty in 1964 and remained active on campus, cycling into his office every day, until a stroke slowed him down in January of this year. But his impact will last for years.

Wasson co-created the UCLA Meteorite Collection — the largest collection on the West Coast — and was a passionate promoter of science in California. When, in 1975, prospectors discovered a 38-inch iron meteorite in the Old Woman Wilderness in the Mojave Desert, so heavy it had to be excavated from a remote ravine by the U.S. Marines Corps, he corralled politicians from both sides of the aisle in the state legislature to ensure it remained on display in the Golden State rather than at the Smithsonian in Washington, DC. Today a slice of California's biggest meteorite, known as the "Old Woman," is proudly on display in the UCLA Meteorite Collection in the Geology Building.

"While his passion for science, eloquence and warmth transformed many UCLA faculty and students into cosmochemistry enthusiasts, his dedication to the meteorite gallery helped tens of thousands of visitors gain a deeper appreciation for the secrets of the solar system," said Miguel García-Garibay, dean of the division of physical sciences. "It is only fitting that his legacy and influence will remain forever in those celestial bodies, some of which, not surprisingly, carry the mineral 'wassonite,' a form of titanium sulfide that was named in his honor," García-Garibay said.

Always a rebel, Wasson helped lead an insurrection still remembered in relevant scientific circles. In 1966, the enthusiasts who ran the venerable Meteoritical Society were swept away wholesale during elections and replaced by professionals — a sign times were changing, he said later. And for the next five decades at UCLA Wasson helped remake the science behind the global study of meteorites.

Alan Rubin, co-curator of the UCLA Meteorite Collection, said that over the decades his colleague's work evolved through three areas of interests.

"He arrived at UCLA at the right time, during the NASA Apollo missions to the Moon when scientists were for the first time able to study lunar samples brought back from the surface," Rubin said.

His chemical approach resulted in a memorable acronym KREEP, constructed from the letters K (for potassium), REE (rare-Earth elements), and P (phosphorus). It is the geochemical mixture found in some lunar rocks that supports the hypothesis that the Moon was originally a ball of hot magma rather than an always-cold rock.

Wasson became a global leader in the study of meteorites, and what they reveal about the formation of the solar system, Rubin said. Wasson wrote two books and published more than 300 articles on the chemical and petrologic properties of meteorites.

He became president of the Meteoritical Society and was awarded its highest honor, the Leonard Medal, in 2002. That was followed the next year by the J. Lawrence Smith Medal from the National Academy of Sciences.

Wasson became a leading expert in the relatively rare iron meteorites and the more common but amazingly varied form of space rock known as chondrites. He remained fascinated by chondrules, tiny round grains found inside chondrites, which are amongst the oldest and most basic building blocks of the solar system. He argued they were formed by repeated melting, maybe by lightning, and then stuck together within ice and dust on an asteroid.

In his later years Wasson also become interested in tektites, said his colleague Kevin McKeegan, and went hunting in Thailand and Laos for these gravel-sized glass fragments created when a meteorite hits the ground. He found they could be dispersed across a massive area, as much as 100,000 square kilometers. He argued that could be caused by air-bursts, in contrast to the classical narrative of cratering events.

— Text courtesy of The Meteoritical Society

NASA ASKS: What's in Your #NASAMoonKit?

How to Share Your #NASAMoonKit: To share your kit, upload a photo or video to Instagram, Twitter or Facebook, and include #NASAMoonKit in the posts.

The digital movement will lead into the agency's Green Run rocket test planned for November. With the Space Launch System (SLS) rocket's core stage anchored in a test stand at NASA's Stennis Space Center near Bay St. Louis, Mississippi, NASA will fire up the powerful stage and fire its four engines for up to eight minutes. That test, known as a hot fire, is the first time the core stage will be operated and the last in a critical series of Green Run tests for the stage before the rocket is assembled for flight at NASA's Kennedy Space Center in Florida. The next time the core stage will fire up again will be for the Artemis I launch next year.

Submissions that catch the digital team's eye will be shared on NASA's social media accounts or as part of the Green Run broadcast next month. Additional terms and conditions are posted online.

Can't decide what to pack or looking for other ways to get involved? NASA also has regular opportunities to provide solutions to NASA while winning prizes and more through its NASA Solves website. A few of the current challenges available right now are:

Lunar Deep Freeze Challenge
Moon Pod Essay Contest
Watts on the Moon Challenge
NASA recently published a written plan detailing its Artemis program, including the latest Phase 1 plan to land astronauts on the Moon again within four years. That plan accompanies the agency's concept for surface sustainability released earlier this year, which calls for an incremental buildup of infrastructure on the surface later this decade. Ultimately, NASA will use what it learns on and around the Moon to prepare for humanity's next giant leap: sending the first astronauts to Mars as early as the 2030s.

Learn more about NASA's Artemis program at www.nasa.gov/artemis.

NASA SEEKS IDEAS FROM THE PUBLIC FOR POWERING EXPLORATION ON THE MOON

NASA's Watts on the Moon Challenge — the agency's newest public prize competition — is now open and accepting submissions. NASA invites innovative minds from across the United States to provide ideas for sustainable energy storage, distribution, and management on the lunar surface.

As part of the Artemis program, NASA will send astronauts to new areas of the Moon including the lunar South Pole, and prepare for human exploration of Mars. As noted in the agency's recent lunar surface report, sustainable missions will require an unprecedented capacity for power. Astronauts will need a continuous supply of power from multiple sources to live and work on the Moon for long periods. A flexible and robust system for surface power is key to safe and robust lunar exploration.

The Goal

On much of the Moon's surface, daylight lasts a little over 14 Earth days, followed by 14 days of darkness and extremely cold temperatures. State-of-the-art power systems cannot operate in such harsh conditions. While sunlight is more available at the lunar poles, there are irregular periods of darkness and locations, like within craters, where the Sun never shines. Existing state-of-the-art power systems cannot operate in such harsh conditions or are too heavy and bulky for flight.

NASA is developing technologies to

provide sustainable power through the extreme environments of the lunar night, including fission surface power, solar power, and regenerative fuel cells. The Watts on the Moon Challenge complements those efforts by focusing on technologies to distribute, manage, and store energy generated by different sources.

Similarly, terrestrial energy needs, utility business models, and customer demands for renewable energy are evolving to necessitate new solutions for power distribution, power management, energy storage, and thermal storage. Not only could novel solutions make a difference in lunar and space exploration, but technologies discovered during NASA's Watts on the Moon competition could help facilitate new power options on Earth.

The Competition

The Watts on the Moon competition will take place over multiple phases. For Phase 1 of the competition, participants will design a flexible and robust system capable of addressing one or more of three hypothetical mission activities similar to a real lunar mission. Solutions to this challenge will advance technology by developing energy distribution, management, and storage that can facilitate initial human presence on the Moon.

Individuals and teams interested in participating in the challenge can register and submit concept designs until 5 p.m. EDT on March 25, 2021. Winners will be awarded a portion of the $500,000 prize purse.

Depending on the outcome of the design competition, a second phase could task participants to build working prototypes that demonstrate their solutions. Phase 2 prizes are expected to total $4.5 million and could involve testing at a NASA or third-party facility.

The Watts on the Moon Challenge is managed by NASA Glenn Research Center, and is part of NASA's Centennial Challenges, based at NASA's Marshall Space Flight Center in Huntsville, Alabama. Centennial Challenges is a part of the Prizes and Challenges program within NASA's Space Technology Mission Directorate. NASA Centennial Challenges has contracted HeroX to support the execution of this challenge.

To learn more about the challenge and register to participate, visit nasa.gov/wattson.

NASA AWARDS FELLOWSHIPS TO ADVANCE EXPLORATION, INCREASE MINORITY STEM OPPORTUNITIES

NASA has awarded 17 fellowships to minority-serving institutions, through its Minority University Research and Education Project (MUREP), and an additional five fellowships to other universities through mission directorate project funds. The awards begin in the 2020 academic year and total more than $3 million to support innovative graduate student research.

The selected projects include research into the dynamics of Mars' atmosphere, satellite communications, solar technologies, and other areas that have the potential to contribute directly to NASA's missions, including returning America to the Moon through the Artemis program.

The recipient institutions of MUREP-funded fellowships are:

- New Mexico State University, in Las Cruces
- University of New Mexico, in Albuquerque
- University of California, Davis
- Texas Tech University, in Lubbock
- University of Central Florida, in Orlando (two awards)
- Florida International University, in Miami (three awards)
- University of Maryland, Baltimore County
- San Diego State University, in California
- University of California, Santa Cruz
- University of Nevada, Las Vegas
- University of California, Irvine (three awards)

- University of California, Santa Barbara
-

The recipient institutions of center-funded fellowships, provided by NASA's Aeronautics Research, Science, Human Exploration and Operations, and Space Technology Mission Directorates, are:

- University of Michigan, Ann Arbor (two awards)
- University of Miami, Coral Gables, Florida
- Rensselaer Polytechnic Institute, in Troy, New York
- Vanderbilt University, in Nashville, Tennessee

The awards provide for a potential fourth-year extension based on the institution's ability to build on their accomplishments of the first three years.

For more information on these fellowship awards and the projects they will fund, visit go.nasa.gov/391HujW.

NASA AWARDS GRANTS TO MINORITY SERVING INSTITUTIONS TO IMPROVE PARTICIPATION IN ENGINEERING

NASA has awarded 14 planning grants to Minority Serving Institutions (MSIs) through its Minority University Research and Education Project (MUREP), part of the agency's Office of STEM Engagement. The grants, totaling more than $587,000, are part of a phased partnership effort with the National Science Foundation (NSF).

The grants will encourage the development of coalitions aimed at broadening participation in engineering, in alignment with the goals of the NSF Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (INCLUDES) initiative.

Continuing to invest in MSIs is an ongoing priority for MUREP. Through these planning grant awards, the lead MSIs have developed coalitions with a variety of partners, including other MSIs, non-MSIs, industry, non-profit organizations and other non-governmental organizations.

The recipient institutions are:

California State University, Northridge
Growing Engineering Engagement in Underserved and Underrepresented Populations

California State University, San Bernardino
Partnerships for Recruitment, Retention, Research and Mentoring for Engineering

Florida A&M University
NASA MUREP-NSF INCLUDES Fueling Opportunities for Successful Engineering Retention of Non-Traditional STEM (FOSTER-NTS) Majors into PhD Programs at the FAMU-FSU College of Engineering

Navajo Technical College
NASA–Navajo Nation Ne-tdale Ak'is: Expanding Partnerships

Navajo Technical College
Integration of Earth and Space Science initiatives in Engineering Curriculum and community engagement at Navajo Technical University

New Mexico State University, Las Cruces
Coalition for Growing a Diverse Workforce to Develop and Commercialize the Next Generation of Space-Based Technologies

North Carolina A&T State University, Greensboro
iCASE: Inclusive Consortium of Autonomous Systems Engineers

Southern University, Baton Rouge, Louisiana
STEM^3 in South-East Louisiana

Texas A&M University, Kingsville
Parallel Pathways of Excellence to Engage Minority Students in Aerospace Engineering

University of Arkansas, Pine Bluff
Developing a Community of Space Scientists

University of Hawaii, Honolulu
Planning and Development for a Sustainable STEM-Outreach Program: Hawai'i's Aspiring Engineers Academy

University of Massachusetts, Boston
Partners Aligned To Heighten broad participation in STEM (PATHS)

University of Texas, El Paso
Coalition for Inspiration, Education and Research in Electrical and Computer Engineering at Hispanic Serving Institutions (ECE@HSI)

University of Texas, San Antonio
City-based Integrated Engineering Training Alliance to Engage, Educate and Empower the Next Generation STEM Workforce

About MUREP

NASA's Minority University Research and Education Project supports the training and development of students and faculty at MSIs in STEM fields by providing opportunities for research and

education that inspires and prepares minority students for STEM careers.

An integral part of this mission, NASA MUREP INCLUDES was established to strengthen and develop the research capacity and infrastructure of minority-serving institutions in areas of strategic importance and value to NASA's mission and national priorities.

For more information about MUREP, visit www.nasa.gov/stem/murep/.

NASA SELECTS PROPOSALS FOR NEW SPACE ENVIRONMENT MISSIONS

NASA has selected five proposals for concept studies of missions to help improve understanding of the dynamics of the Sun and the constantly changing space environment with which it interacts around Earth. The information will improve understanding about the universe as well as offer key information to help protect astronauts, satellites, and communications signals — such as GPS — in space.

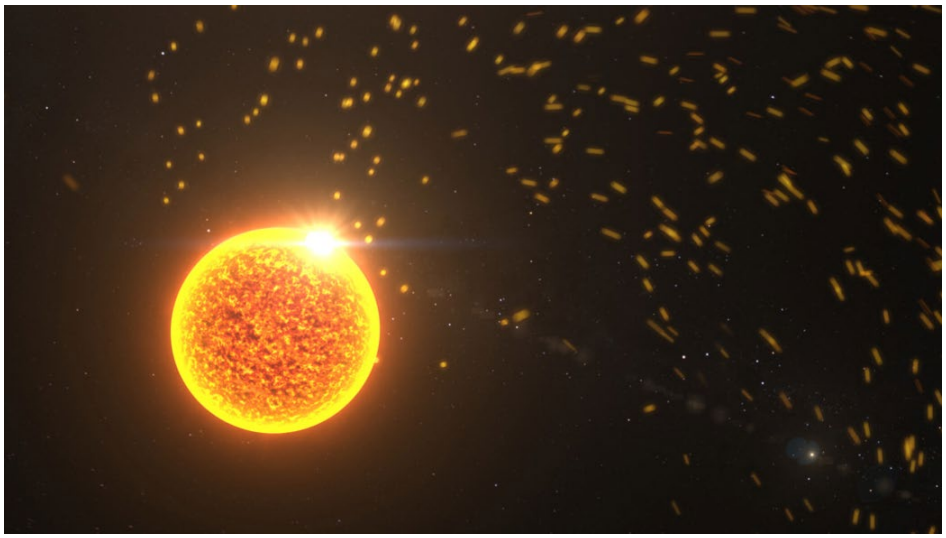
Each of these Medium-Class Explorer proposals will receive $1.25 million to conduct a nine-month mission concept study. Following the study period, NASA will choose up to two proposals to go forward to launch. Each potential mission has a separate launch opportunity and timeframe.

NASA's heliophysics program explores the giant, interconnected system of energy, particles, and magnetic fields that fills interplanetary space, a system that constantly changes based on outflow from the Sun and its interaction with the space and atmosphere around Earth.

Each of these new proposals seeks to add a new puzzle piece to understanding that larger system, some by looking at the Sun, some by making observations closer to home.

The proposals were selected based on potential science value and feasibility of development plans. The cost for the investigation ultimately chosen for flight will be capped at $250 million and is funded by NASA's Heliophysics Explorers' program.

The proposals selected for concept studies are:



Solar-Terrestrial Observer for the Response of the Magnetosphere (STORM)

STORM is led by David Sibeck at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

HelioSwarm: The Nature of Turbulence in Space Plasmas

HelioSwarm is led by Harlan Spence at the University of New Hampshire in Durham.

Multi-slit Solar Explorer (MUSE)

MUSE is led by Bart De Pontieu at Lockheed Martin in Palo Alto, California.

Auroral Reconstruction CubeSwarm (ARCS)

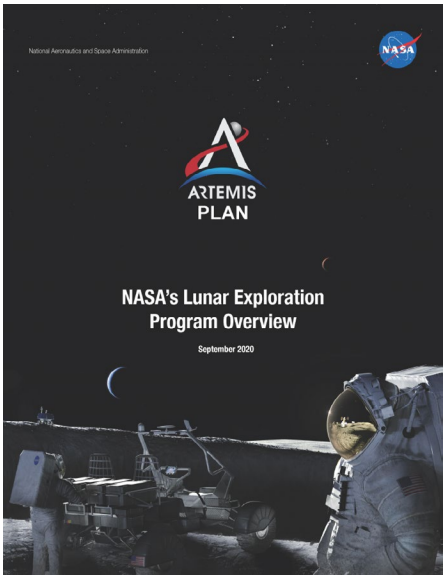
ARCS is led by Kristina Lynch at Dartmouth University in Hanover, New Hampshire.

Solaris: Revealing the Mysteries of the Sun's Poles

Solaris is led by Donald Hassler at the Southwest Research Institute in Boulder, Colorado.

For information about NASA and space science, visit www.nasa.gov/sunearth.

NASA PUBLISHES ARTEMIS PLAN TO LAND FIRST WOMAN, NEXT MAN ON MOON IN 2024



Following a series of critical contract awards and hardware milestones, NASA has shared an update on its Artemis program, including the latest Phase 1 plans to land the first woman and the next man on the surface of the Moon in 2024.

In the 18 months since NASA accepted a bold challenge to accelerate its exploration plans by more than four years and establish sustainable exploration by the end of the decade, the agency has continued to gain momentum toward sending humans to the Moon again for the first time since the last Apollo lunar mission in 1972.

In its formal plan, NASA captures Artemis progress to date, identifying the key science, technology, and human missions as well as the commercial and international partnerships that will ensure we continue to lead in exploration and achieve our ambitious goal to land astronauts on the Moon.

The agency's powerful new rocket, the Space Launch System (SLS), and the Orion spacecraft are closer than ever to their first integrated launch. The spacecraft is complete while the core stage and its attached four engines are undergoing a final series of tests that will culminate in a critical hot fire test this fall.

Learn more about NASA's Artemis program at www.nasa.gov/artemis.

NASA REPORT DETAILS HOW AGENCY SIGNIFICANTLY BENEFITS U.S. ECONOMY

NASA released the results of its first-ever agencywide economic impact report. The report shows that, through all NASA activities, the agency generated more than $64.3 billion in total economic output during fiscal year 2019, supported more than 312,000 jobs nationwide, and generated an estimated $7 billion in federal, state, and local taxes throughout the United States.

The agency commissioned an economic impact study to better understand how the U.S. economy benefited in FY2019 from America's lunar and Mars exploration efforts. The study found the agency's Moon to Mars exploration approach generated more than $14 billion in total economic output and supported more than 69,000 jobs nationwide in fiscal year 2019.

Additional key findings of the study include:

- Every state in the country benefits economically through NASA activities. Forty-three states have an economic impact of more than $10 million. Of those 43 states, eight have an economic impact of $1 billion or more.
- The agency's Moon to Mars initiative, which includes the Artemis program, supports more than 69,000 jobs, $14 billion in economic output, and $1.5 billion in tax revenue. The agency's Moon to Mars programs provided about 22% of NASA's economic impact. These figures are expected to double in 2021.
- NASA has more than 700 active international agreements for various scientific research and technology development activities in FY2019. The International Space Station is a significant representative of international partnerships — representing 15 nations and five space agencies — and has been operating for 20 years.
- NASA spinoff technologies provide an impact on American lives beyond dollars and jobs. The agency has recorded more than 2000 spinoffs since 1976. For example, engineers at NASA's Jet Propulsion Laboratory developed, in just 37 days, a ventilator specifically for coronavirus patients and, after securing an emergency use authorization from the Food and Drug Administration, made the design available to select manufacturers at no cost.
- Scientific research and development — which fuels advancements in science and technology that can help improve daily life on Earth and for humanity — enjoys the largest single-sector impact, accounting for 16% of the overall economic impact of NASA's Moon to Mars program.

The study was conducted by the Nathalie P. Voorhees Center for Neighborhood and Community Improvement at the

University of Illinois at Chicago (UIC). UIC has worked with NASA's Marshall Space Flight Center on economic impact reports conducted for the center and the Voorhees Center is widely recognized as one of the foremost organizations conducting economic impact studies for corporations, communities, and government agencies.

A summary of the study is available at go.nasa.gov/3cxsYlU.

NASA, U.S. SPACE FORCE ESTABLISH FOUNDATION FOR BROAD COLLABORATION

While advancing plans for unprecedented lunar exploration under the Artemis program, NASA also is building on a longstanding partnership with the Department of Defense with a new memorandum of understanding announced by NASA Administrator Jim Bridenstine and U.S. Space Force (USSF) Chief of Space Operations Gen. John "Jay" Raymond.

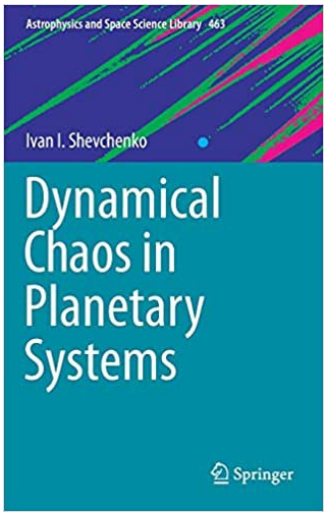
The agreement, discussed during a September 22 Mitchell Institute virtual event, commits the two organizations to broad collaboration in areas including human spaceflight, U.S. space policy, space transportation, standards and best practices for safe operations in space, scientific research, and planetary defense.

The memorandum replaces an agreement signed 14 years ago between NASA and the U.S. Air Force Space Command, under which the two organizations exchanged research and development information, sought to reduce duplication of system development, and collaborated in the long-term planning of each organization's space roadmaps.

Freedom of action in space provides NASA and allied-nation space agencies the ability to explore and discover, and will enable America's return to the Moon and subsequent exploration of Mars. The USSF will secure the peaceful use of space, free for any who seek to expand their understanding of the universe, by organizing, training, and equipping forces to protect U.S. and allied interests in space.

For the full press release, visit www.nasa.gov/press-release/nasa-us-space-force-establish-foundation-for-broad-collaboration.

NEW AND NOTEWORTHY

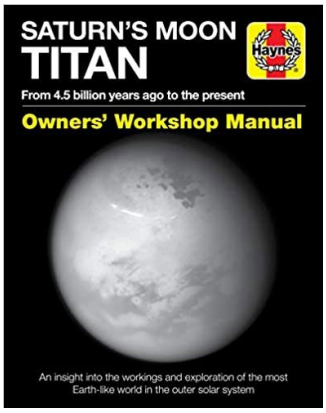


DYNAMICAL CHAOS IN PLANETARY SYSTEMS

By Ivan Shevchenko

Springer, 2020, 376 pp., Hardcover. $159.00. www.springer.com

This is the first monograph dedicated entirely to problems of stability and chaotic behavior in planetary systems and its subsystems. The author explores the three rapidly developing interplaying fields of resonant and chaotic dynamics of Hamiltonian systems, the dynamics of solar system bodies, and the dynamics of exoplanetary systems. The necessary concepts, methods, and tools used to study dynamical chaos (such as symplectic maps, Lyapunov exponents and timescales, chaotic diffusion rates, stability diagrams, and charts) are described and then used to show in detail how the observed dynamical architectures arise in the solar system (and its subsystems) and in exoplanetary systems. The book concentrates on chaotic diffusion and clearing effects. The potential readership of this book includes scientists and students working in astrophysics, planetary science, celestial mechanics, and nonlinear dynamics.



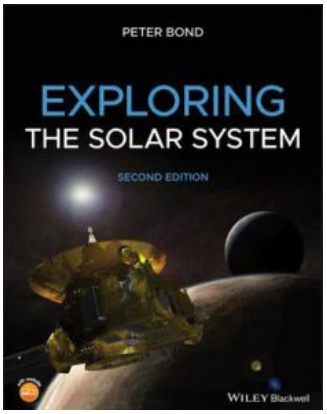
SATURN'S MOON TITAN OWNERS' WORKSHOP MANUAL: From 4.5 Billion Years Ago to the Present

By Ralph Lorenz

Haynes Publishing, 2020, 200 pp., Hardcover. $36.95. www.quartoknows.com

Titan is a moon of Saturn, most recently explored by the Cassini/Huygens probes. Titan is of huge interest to scientists, as the conditions in its atmosphere and on its surface bear a striking similarity to those of early Earth. It is thought that there is a realistic possibility that forms of primitive life could develop — or may already have developed — on the surface or in the oceans of Titan. As a result, there are plans to send further probes to Titan in order to further explore the conditions on its surface and in its oceans. The theme of Saturn's Moon Titan Owners' Workshop Manual is how Titan works "as a planet," with an emphasis on illustrating the features and processes of Titan — where the conditions and materials can be exotic — with familiar analogs from the Earth or other planets. The book includes numerous images from the field, the air, and satellites to show comparable features on Earth or other planets. The final chapter discusses Titan in practical terms as an environment for humans in the future, bringing the place "to life." Images of geographical and geological features on Earth illustrate the parallels with Titan, and the book explores some of the innovative ideas for scientific probes — including airships, landers, a submarine, and a drone — being looked at to further explore Titan on future missions. The author was closely involved with the Cassini/Huygens project, which explored Titan during its mission to Saturn, and has also played a major role in the definition of a range of U.S. and European concepts for future missions to Titan. He is currently working on a design study adopted by NASA for a quadcopter probe named "Dragonfly," which it is hoped will be developed to explore Titan.

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

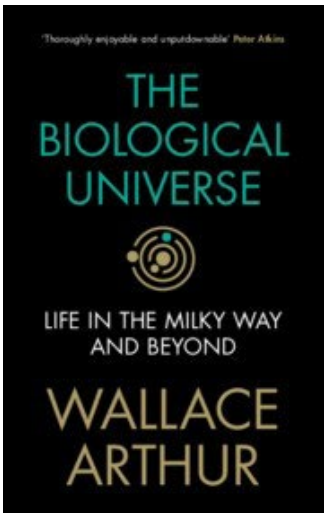


EXPLORING THE SOLAR SYSTEM, 2ND EDITION

By Peter Bond

Wiley, 2020, 552 pp., Paperback. $100.00. www.wiley.com

Exploring the Solar System is an exciting and authoritative account of the second Golden Age of solar system exploration. Award-winning author Peter Bond provides an up-to-date, indepth account of the Sun and its family in this second edition. This new edition brings together the discoveries and advances in scientific understanding made during the last 60 years of solar and planetary exploration, using research conducted by the world's leading geoscientists, astronomers, and physicists. This book is an ideal introduction for non-science undergraduates and anyone interested in learning about our small corner of the Milky Way galaxy.

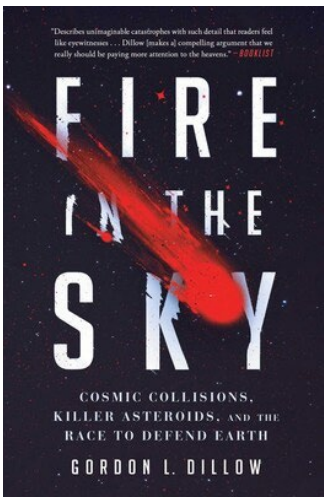


THE BIOLOGICAL UNIVERSE: Life in the Milky Way and Beyond

By Wallace Arthur

Cambridge University Press, 2020, 255 pp., Hardcover. $24.95. www.cambridge.org

Are we alone in the universe, or are there other life forms "out there"? This is one of the most scientifically and philosophically important questions that humanity can ask. Now, in the early 2020s, we are tantalizingly close to an answer. As this book shows, the answer will almost certainly be that life forms are to be found across the Milky Way and beyond. They will be thinly spread, to be sure, yet the number of inhabited planets probably runs into the trillions. Some are close enough for us to detect evidence of life by analyzing their atmospheres. This evidence may be found within a couple of decades. Its arrival will be momentous. But even before its arrival, we can anticipate what life elsewhere will be like by examining the ecology and evolution of life on Earth. This book considers the current state of play in relation to these titanic issues.



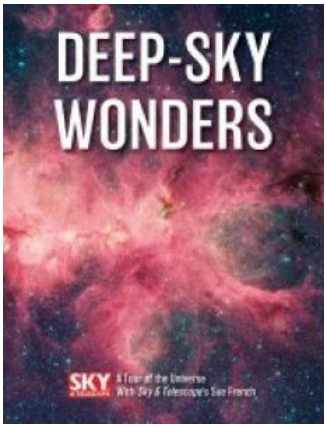
FIRE IN THE SKY: Cosmic Collisions, Killer Asteroids, and the Race to Defend Earth

By Gordon L. Dillow

Scribner, 2020, 288 pp., Paperback. $17.00. www.simonandschuster.com

One of these days, warns author Gordon Dillow, the Earth will be hit by a comet or asteroid of potentially catastrophic size. The only question is when. In the meantime, we need to get much better at finding objects hurtling our way, and if they're large enough to penetrate the atmosphere without burning up, figure out what to do about them. We owe many of science's most important discoveries to the famed Meteor Crater, a mile-wide dimple on the Colorado Plateau created by an asteroid impact 50,000 years ago. In this book, Dillow unpacks what the crater has to tell us. Prior to the early 1900s, the world believed that all craters — on the Earth and Moon — were formed by volcanic activity. Not so. The revelation that Meteor Crater and others like it were formed by impacts with space objects has led to a now-accepted theory about what killed off the dinosaurs, and it has opened up a new field of asteroid observation that is brimming with urgency. Dillow looks at great asteroid hits of the past and modern-day asteroid hunters and defense planning experts, including America's first Planetary Defense Officer. Both a work of popular science and a warning to not take for granted the space objects hurtling overhead, this book is ultimately a testament to our universe's celestial wonders.

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

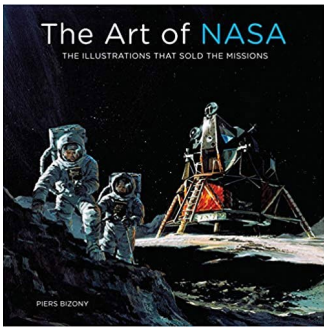


DEEP SKY WONDERS: A Tour of the Universe with Sky & Telescope's Sue French

By Sue French

Firefly Books, 2020, 320 pp., Paperback. $29.95. www.fireflybooks.com

Sue French writes the popular column "Deep-Sky Wonders" for Sky & Telescope magazine and teaches deep-sky observation. This book is a collection of 100 of French's best "Deep-Sky Wonders" columns originally published in Sky & Telescope, which has a monthly readership exceeding 100,000. The book is organized by season and subdivided into months for a total of 100 indepth tours of the deep sky. Each tour illuminates little-known seasonal wonders that lie off the beaten path. The book features full-color photographs and detailed sketches of each deep sky tour, historical and scientific background of particular interest, a tabular listing of the deep-sky sites, color charts showing the position of each target in the night sky, and more. Deep-Sky Wonders also features a variety of challenging objects that encourage observers to test the limits of their equipment and skills. This book is suitable for beginner and intermediate small-scope astronomers as well as large-scope viewers and astrophotographers. It is also an outstanding introduction to deep-sky viewing for novice observers.



THE ART OF NASA: The Illustrations that Sold the Missions

By Piers Bizony

Motorbooks, 2020, 192 pp., Hardcover. $50.00. www.quartoknows.com

Formed in 1958, NASA has long maintained a department of visual artists to depict the concepts and technologies created in humankind's quest to explore the final frontier. Culled from a carefully chosen reserve of approximately 3000 files deep in the NASA archives, the 200 artistic works presented in this large-format edition provide a glimpse of NASA history like no other. From space suits to capsules, from landing modules to the space shuttle, the International Space Station, and more recent concepts for space planes, The Art of NASA presents 60 years of American space exploration in an unprecedented fashion. All the landmark early missions are represented in detail — Gemini, Mercury, Apollo — as are post-Space Race accomplishments, like the mission to Mars and other deep-space explorations. The insightful text relates the wonderful stories associated with the art. For instance, the incredibly rare early Apollo illustrations show how Apollo might have looked if the landing module had never been developed. Black-and-white Gemini drawings illustrate how the massive NASA art department did its stuff with ink pen and rubdown Letraset textures. Cross-sections of the Apollo-Soyuz Test Project docking adapter reveal Russian sensitivity about U.S. "male" probes "penetrating" their spacecraft, thus the androgynous "adapter" now used universally in space. International Space Station cutaways show how huge the original plan was, but also what was retained. Every picture in The Art of NASA tells a special story. This collection of the rarest of the rare is not only a unique view of NASA history — it's a fascinating look at the art of illustration, the development of now-familiar technologies, and a glimpse of what the space program might have looked like.

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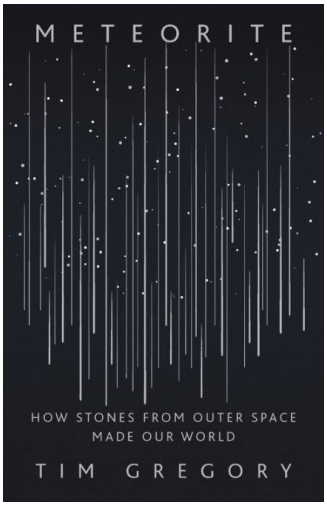
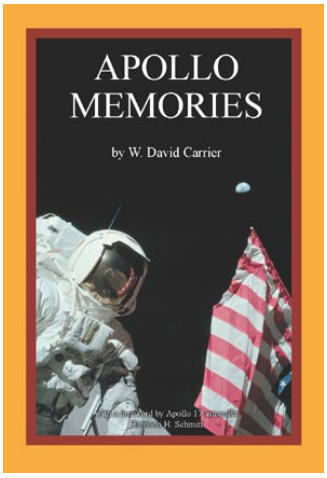


METEORITE: How Stones from Outer Space Made Our World

By Tim Gregory

Basic Books, 2020, 320 pp., Paperback. $17.99. www.basicbooks.com

Meteorites have long been seen as portents of fate and messages from the gods, their fiery remains inspiring worship and giving rise to legends that have persisted for millennia. But beyond the lore, meteorites tell an even greater story: that of our solar system. In Meteorite, geologist Tim Gregory shows that beneath the charred crusts of these celestial stones lies a staggering diversity of rock types. Their unique constituents, vibrant colors, and pungent smells contain thrilling tales of interstellar clouds, condensing stardust, and the fiery collisions of entire worlds. Gregory explores the world of meteorites to uncover new insights into what our solar system was like before our Sun became a star, into the forging of our planet, and into the emergence of life on it. Humans have long looked to the skies for answers to big questions. Meteorite reveals how science is finally arriving at those answers.



APOLLO MEMORIES

By W. David Carrier

CG Publishing, 2020, 144 pp., Paperback. $26.95. www.cgpublishing.com

Apollo Memories is the personal memoir of Dr. W. David Carrier, one of the scientists who prepared the Apollo astronauts to do science on another world. Carrier was responsible for the development and performance of lunar soil experiments in support of the Apollo program at the NASA Manned Spacecraft Center in Houston. His activities included astronaut training, design of lunar surface experiments, and laboratory testing of returned lunar soil. It was Carrier who told Neil Armstrong and Buzz Aldrin how deep they were going to sink into the lunar surface. He was a member of the science support team in Mission Control and a member of the Lunar Sample Preliminary Examination Team in the Lunar Receiving Laboratory during each of the Apollo missions. In this book, using his own words and some of the most famous photographs ever taken, Carrier takes the reader back to the heady days of the first manned lunar explorations and puts the science into context. Although 40,000 people worked on the Apollo program, only a select few were given the opportunity to directly work with the astronauts to prepare them for humankind's greatest adventure. Carrier earned that opportunity. The book includes images in color and some anaglyphs, explained by the man who asked them to be taken, and comes with red/blue glasses.

SPACE BATH BOMBS

Produced by Lil Picasso

Set of nine large solar system bath bombs. $16.90. Available from Amazon.com

This set of nine solar system bath bombs is designed to entice children's curiosity and make bath time fun. Just drop a planet bath fizzer into a tubful of water and enjoy the magical color and fragrance. These bath bombs are safe and made of natural ingredients. The set comes with space information cards, educational tools to set the spark to the journey into deep space, and a scratch-and-sketch notepad for etching the night sky. For toddlers, teens, and adults.

PLANET MUG

Available from the Unemployed Philosophers Guild

$15.95. www.philosophersguild.com

This 12-ounce mug features beautiful original portraits of our solar system, and every time you enjoy a hot cup of coffee or cocoa, you can learn about each planet. The heat from your favorite hot drink transforms the mug into a planetarium in your hand, revealing unique features of our planet, solar system, and galaxy. This mug is not dishwasher-safe but is microwave-safe.

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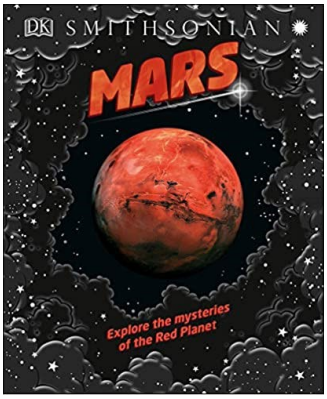
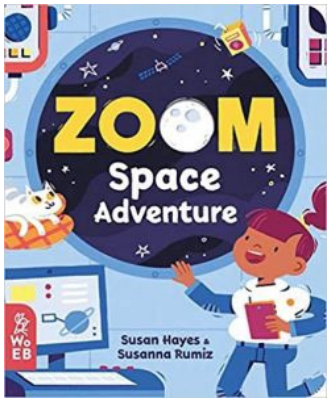


MARS: Explore the Mysteries of the Red Planet

DK Children, 2020, 80 pp., Hardcover. $16.99. www.dk.com

Has there ever been life on Mars? Will we be living there soon? HOW?! Discover the past, present, and future of the mysterious Red Planet in this beautiful nonfiction book for kids. The launch of Mars rovers by NASA, Europe, and China in 2020 is the biggest science news of the year, and these missions will reveal more about Mars than ever before. Get ahead with this amazing new book, which explores the evidence for past life on Mars, what's happening there now, and what it might look like to one day live on the Red Planet. Be amazed by the tallest mountain in the solar system, discover how houses on Mars could look, and find out if you've got what it takes to join the teams traveling to Mars in the coming years. Children will adore this essential guide to Mars. Incredible images and fun illustrations will ignite their imagination and give them a fascinating insight into what the future might hold. For ages 7 to 9.

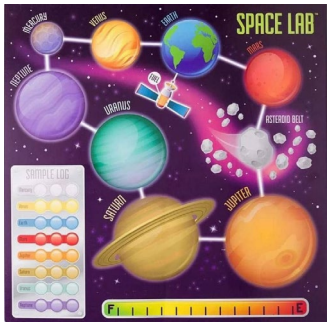


ZOOM SPACE ADVENTURE

By Susan Hayes

What on Earth Books, 2020, 36 pp., Board book. $14.99. www.whatonearthbooks.com

Blast off to adventure! Join Ava and her cat on their adventure into space, where you can visit the International Space Station, ride in a Moon buggy, discover a Mars rover, journey past all the planets in the solar system, and watch the greatest show in outer space: a supernova explosion. Die-cut board pages and a pop-up make every page an interactive experience, keeping readers guessing about what surprise awaits on the next page, while fun and informative writing explains fascinating facts about space. For ages 1 to 3.

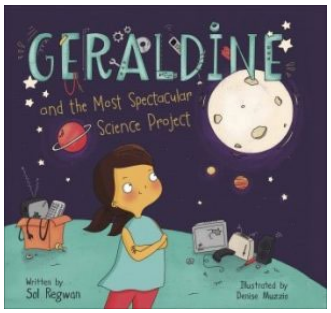


SPACE LAB BOARD GAME

Produced by Hearthsong

$21.98. www.hearthsong.com

Take a trip to outer space with the Space Lab Board Game. It's a playful, other-worldly way to learn the names and order of the planets in our solar system. Kids can take a magical ride around the cosmos in rockets while collecting samples from each planet before running out of fuel. Watch out for the asteroid belt! This game teaches kids about the solar system and organizes data in a simple, easy-to-understand chart. While playing this exciting space game, kids are also building skills in strategy, social play, and cooperation. For ages 3 and up.



GERALDINE AND THE MOST SPECTACULAR SCIENCE PROJECT

By Sol Regwan

Schiffer Publishing, 2020, 32 pp., Hardcover. $16.99. www.schifferbooks.com

Geraldine is an energetic, spirited second grader with dreams of becoming an astronaut. She knows that she's clever and inventive, but can she create the winning entry in her class science contest? Armed with nothing but her strong will and the broken parts of her parents' old gadgets and gizmos, she sets out to invent an amazing contraption. Will her invention wow her classmates and transform her from class troublemaker to creative scientist? For ages 5 to 8.

CALENDAR

2020 Upcoming Events

November | December

November

Apophis T-9 Years: Knowledge Opportunities for the Science of Planetary Defense

November 4–6
Online
www.hou.usra.edu/meetings/apophis2020/

Outer Planet Moon-Magnetosphere Interaction Workshop

November 5–6
Noordwijk, Netherlands
https://indico.esa.int/event/337

Astrobiology 2020

November 9–13
Vredefort Dome, South Africa
astrobiology.uj.ac.za/

36th International Geological Congress

November 9–14
New Delhi, India
www.36igc.org/

Threats from the Surroundings: An E-Workshop on the Importance of Environment for the Evolution of Protoplanetary Discs and Formation of Planets

November 10–12
Virtual
www.eso.org/sci/meetings/2020/tfts2020.html

Hera Workshop
November 11–13
Nice, France
www.cosmos.esa.int/web/hera-community-workshop

18th Meeting of the Venus Exploration Group (VEXAG)
November 16–18
Pasadena, California
www.lpi.usra.edu/vexag/meetings/vexag-18/

Magnetism and Accretion
November 16–20
Cape Town, South Africa
ma2020.saao.ac.za/

3rd Annual Interstellar Probe Exploration Workshop
November 17–19
Silver Spring, Maryland
www.hou.usra.edu/meetings/interstellarprobe2020/

5th International Workshop on Instrumentation for Planetary Missions 2020
November 18–20
Tokyo, Japan
www2.rikkyo.ac.jp/web/ipm2020/

Modeling, Observing, and Understanding Flows and Magnetic Fields in the Earth's Core and in the Sun
November 30–December 4
Cambridge, United Kingdom
www.newton.ac.uk/event/dytw03

December

AGU Fall Meeting
December 7–11
San Francisco, California
www.agu.org/

2021 Upcoming Events

January | March | April | June

January

24th Meeting of the NASA Small Bodies Assessment Group

January 26–27

Virtual

www.lpi.usra.edu/sbag/

March

52nd Lunar and Planetary Science Conference

March 15–19

Virtual

www.hou.usra.edu/meetings/lpsc2021/

April

16th Spacecraft Charging and Technology Conference

April 12–16

Cocoa Beach, Florida

www.hou.usra.edu/meetings/sctc2020/

The UK Exoplanet Community Meeting 2021

April 14–16

Birmingham, UK

www.ukexom2020.uk

7th IAA Planetary Defense Conference

April 26–30

Vienna, Austria

iaaspace.org/pdc

May

Heliophysics 2050 Workshop

May 3–5
TBD
www.hou.usra.edu/meetings/helio2050/

Origins and Exploration: From Stars to Cells (AbSciCon)

May 9–14
Atlanta, GA
www.agu.org/abscicon

Distributed Volcanism and Distributed Volcanic Hazards

May 11–15
Flagstaff, AZ
www.agu.org/Chapmans-Distributed-Volcanism

June

Mercury 2021: Current and Future Science of the Innermost Planet

June 8–11
Orléans, France
mercury2020.ias.u-psud.fr/main_1st.php

Asteroids, Comets, Meteors Conference

June 20–25
Flagstaff, Arizona
www.hou.usra.edu/meetings/acm2021/

5th Planetary Data Workshop and Planetary Science Informatics & Data Analytics

June 28 - July 2
Flagstaff, Arizona
www.hou.usra.edu/meetings/planetdata2021/