PERSONAL RECOLLECTIONS OF THE LUNAR AND PLANETARY SCIENCE CONFERENCE

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LUNAR AND PLANETARY INFORMATION BULLETIN

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Personal Recollections of the Lunar and Planetary Science Conference
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Note from the editors: This year marks the 50th anniversary of what is now known as the Lunar and Planetary Science Conference. Originally titled the Apollo 11 Lunar Science Conference, the meeting has since evolved to encompass the entire solar system from Mercury to Ultima Thule. In this article, the author — one of only five scientists who have attended the conference every year since its inception — shares his personal memories, recollections, and behind-the-scenes stories of the history and evolution of what is arguably the premiere planetary science conference in the world. Enjoy! — Paul Schenk and Renée Dotson

The first Lunar Science Conference in January 1970 was actually called the Apollo 11 Lunar Science Conference, at which more than 140 Principal Investigators (PIs) were asked to present the first results about the returned lunar samples in the Albert Thomas Convention and Exhibit Center in downtown Houston. Two of my thesis advisors (first J. Hoover Mackin and later Bill Muehlberger) at the University of Texas at Austin (UT Austin) were members of the Apollo Science Team. Even though Muehlberger would be the geology co-PI for the Apollo 16 and 17 missions, he couldn’t get me into the first meeting since tickets were restricted to PIs and invited guests, not graduate students. But I was able to slip in through a “back door”; the mother of a friend at UT Austin (geology student Ruth Fruland) happened to work in the Public Affairs Office at the Manned Space Flight Center (now the Johnson Space Center) and gave me the equivalent of a Willy Wonka Golden Ticket so I could attend the very first Lunar Science Conference. The conference also included a banquet at the Grand Ballroom of the historic Rice Hotel in downtown Houston. (Interestingly, in 1962 NASA’s Astronaut Group 2 held its first meeting inside that same hotel to plan the next decade of space travel. Among that group was Neil Armstrong, Jim Lovell, and Pete Conrad.)

I roomed with Muehlberger in downtown Houston (Mackin tragically passed away just one year before the landing). Filled with anticipation, I walked to the convention center from the hotel under one of those crisp January days with a deep blue sky. I had my camera with me, but thought it would be “unprofessional” if I took a bunch of photos, especially since I wasn’t sure if I should be there anyway and wanted to maintain a low profile. Besides, I had loaded the camera with color film with a sensitivity that required time exposures in the meeting room. So, I took one photograph of the convention center from the outside and another of the registration desk inside. That was all.

The first Apollo results were presented in a single large room. All the big names were there. Some I had met at a Gordon Research Conference in 1968 or at Apollo team meetings (Don Gault, Mike Duke, Gene Shoemaker, Bill Quaide, Jim Head, and John Wood, to name just a few). But with my camera, I must have looked like a cub reporter. The first meeting naturally focused on sample analysis, but broad themes were already emerging, including Wood’s lunar magma ocean model based on small light-colored particles (anorthosites) discovered in the lunar regolith at the Apollo 11 site. There were no formal abstracts at the first conference, but I picked up one- or two-page summaries that some speakers had left at the registration desk. Actually, NASA had issued a moratorium against publishing anything before the conference, in part because the journal Science would come out with the first results that same week. The second conference in 1971 was again held downtown in January at the same venue. The moratorium against distributing results was lifted, and the first Lunar Science Conference abstract volume contained 241 contributions, a jump of 25% from the first year.

Abstracts then ranged from a single long sentence to several pages (but without a table of contents or index), and revised abstracts were compiled with a pale yellow cover. This year also introduced the first Proceedings of the Lunar Science Conference, edited by the staff of the Lunar Science Institute later that year and published by MIT Press. In addition, 1971 was the year that Soviet scientists were invited to present their results from the Luna 16 automated sample return mission. I recall being really impressed by the tall, buffed Soviet “scientists” who accompanied A. P. Vinogradov in the meeting, not realizing that they must have been bodyguards (or perhaps KGB?).

In 1972, the third Lunar Science Conference moved to the NASA Manned Science Center (MSC) in Clear Lake with sessions in Buildings 1, 17, and 30, and would remain at MSC for the next 30 years. [Note that the Space Center’s name wouldn’t be changed to NASA Johnson Science Center (JSC) until the following year.] The number of submissions had increased to 300 and remained relatively level for the next 5 years. The abstracts had generally expanded to two or three pages and were bound into two separate volumes with yellow covers (hence the references to the conference abstract volumes as the “Yellow Perils”). The fourth Lunar Science Conference in 1973 was again held in Clear Lake, with a “smoker” held in the Holiday Inn Ballroom up the street on NASA Road 1. [Editor’s note: For you young whippersnappers, that’s what cocktail hours were called back in the days when almost everyone smoked.]

The next year, the conference moved to the auditorium in Building 2 (later relabeled Building 1) and Rooms 104 and 206 of the Gilruth Center, which was actually a gym complex at the edge of the NASA JSC campus. In the first few years at the Gilruth Center, one of the gyms remained open during the conference, and you could actually hear basketballs bouncing during the science talks upstairs. The wooded setting of the Gilruth Center lent itself to casual discussions on picnic benches outside. Eventually, the Gilruth Center was essentially closed to athletic activities during the week of the conference, and all sessions were held there in two large halls (converted gyms) on the ground floor and three small rooms above (eventually four).

By then, the “smoker” had moved to the Nassau Bay Hotel (fondly called the “Nausea” Bay by some), which played an important role for many during
the Apollo years. This is where Walter Cronkite gave his on-the-scene black-and-white television reports about the Apollo landings from the top floor, overlooking NASA JSC across the street. One of the most famous (or infamous) social scenes was the “Boom-Boom Room” in the back. This is the place where the Apollo astronauts (and lunar scientists!) let off steam during and after the Apollo missions. Some rooms in the hotel were carpeted from floor to ceiling and even had a glass-enclosed sitting pool. Such great history.

During the late 1960s and early 1970s, the Lunar Science Conference was not the only “planetary” themed conference. In 1968, my primary thesis advisor (Harlan J. Smith) hosted the first meeting of the Division of Planetary Sciences of the American Astronomical Society (DPS) in Austin. I volunteered to be one of the slide-projector operators. However, the DPS meeting focused on planetary atmospheres, dynamics, solar system evolution, and spectrophotometry. I recall one talk that speculated about the surface of Mars. Although Mariner 4 images had captured a few images in 1965, they revealed only craters. One of the attendees (who shall remain nameless) stood up and proclaimed that this was not the conference at which to be talking about surfaces of planets. As a geologist, I thought this was a crushing comment! Conversely, there would be very few planetary astronomy talks at the early Lunar Science Conference, except those about multispectral imaging or photometry of the Moon. Even after the successful planetary missions (Mariner 6, 7, 9, and 10), the first six Lunar Science Conferences included few abstracts about planetary surfaces beyond the Moon, except a half dozen (each year) that placed the Moon in a broader context, such as lunar formation and solar system evolution.

This school of thought reflected three very distinct disciplines (and funding sources) of an emerging new research area: lunar geology, planetary astronomy, and planetary geology. Apollo funding covered the study of lunar geology, while traditional funding for planetary astronomy had a long history (e.g., atmospheres, dynamics, interiors). Funding for planetary geology, however, rode on the coat-tails of the manned mission program to the Moon, enabling the much cheaper Mariner missions (4, 6, 7, 9, 10). Even the Viking mission, which replaced a much more ambitious Voyager mission, was approved by Congress in 1968 at the peak of Apollo funding. Where were the conferences related to planetary surfaces beyond the Moon?

In 1969, one of my other advisors in geology (geochemist F. Earl Ingersoll, known as “Dr. I” by his students) asked if I wanted to look at recently released images from Mariner 6 and 7 to Mars. At that time, NASA Headquarters was soliciting broader participation in planetary geology through small grants. Of course, I said yes. The astronomer Gerard de Vaucouleurs (of UT Austin’s astronomy department) had written books about Mars in the 1940s and published detailed observations. NASA funded him to compile the best photometric map of Mars based on the telescopic observations and photographs. I was asked to help but wanted to see actual features. Even the highest telescopic resolution revealed only irregular smudges and Mariner 4 did little to change this perception, other than to reveal a few craters on the surface, similar to the Moon. The first published reports about Mariner 6 and 7 seemed to support this conclusion, but others interpreted linear features as fault or joint systems. Using cross-correlations among images, I found these “faults” to be artifacts, coherent noise introduced during processing. Left over, however, were sinuous lines that I interpreted as narrow river-like valleys, broken-up terrains, and even portions of Valles Marineris (before seeing any Mariner 9 images). Dr. I asked if I would give a talk about my results at a PI meeting in Flagstaff, Arizona (my first professional talk). This 1969 meeting was the precursor to the Planetary Geology Principal Investigator’s (PGPI) conferences, which paralleled the Lunar Science Conference.

From the very beginning, then, I had my foot in all three “tribes” and enjoyed the very different perspectives and approaches, all the while observing science politics (and trying to stay out of them). This personal diversion is key for understanding and appreciating the later evolution of the Lunar
Science Conference in the 1970s.

Apollo 17 would become the last human landing on the Moon at the end of 1972. Two upcoming landings were canceled; NASA's budget was cut; and some funds were redirected toward international cooperative programs, such as SkyLab (and later the Shuttle Program). It became apparent that new samples would not be coming back from the Moon, and there was a major shift in research emphasis that would transform future Lunar Science Conferences. Moreover, the Apollo program had ended in 1975, and some thought that lunar science should end as well. NASA Centers were told to identify their own role and mission (and avoid overlap). For example, the Planetary Geology Branch at NASA Ames was dissolved, and the Astrogeology Division at the U.S. Geological Survey redirected all its efforts to the upcoming Viking mission. I just happened to be on a train ride from San Jose to the Jet Propulsion Laboratory (NASA HQ asked me to select images for a planned Mercury Atlas) and was surprised to find acquaintances from Astrogeology at Menlo Park going to Flagstaff. They knew that this was more than a train ride: It represented the end of a 20-year journey of studying the Moon. In Flagstaff, they would be told to drop lunar research. I joined them for drinks in the upstairs glass-domed club on a gloomy ride before getting off the train in Pasadena.

NASA's funding shift resulted in a new emphasis on meteorites and terrestrial analog studies . . . along with new strategies to return samples from Mars. The outlook for a career in lunar science from 1973 through 1977, however, seemed grim. Yet the number of abstracts for the seventh and eighth Lunar Science Conferences (1976 and 1977) increased, along with just a few more dealing with objects other than the Moon. Lunar science was still holding on.

I moved from NASA Ames Research Center (as an NRC Post-Doc) to the Lunar Science Institute (now the Lunar and Planetary Institute) in Houston in 1976 (and ironically stayed in the Nassau Bay Hotel while waiting for our moving truck). That year, Robert ("Bob") Pepin, then the Lunar Science Institute Director, initiated the Basaltic Volcanism Study Project (BVSP), which gathered a broad group of scientists to compare the nature, composition, and timing of volcanism on Earth, the Moon, Mercury, and Mars. This required a close look at lunar samples in a much broader planetary context. The next Lunar Science Institute Director (Tom McGetchin) in 1977 breathed life into the BVSP that stimulated new research at subsequent conferences.

In 1978, McGetchin formally changed the name of the Lunar Science Institute to the Lunar and Planetary Institute (LPI), and changed the name of the conference to the Lunar and Planetary Science Conference (LPSC). In addition, opportunities for post-Apollo research expanded through the Lunar Data Analysis and Synthesis Program (championed by Bill Quaide at NASA HQ), which was the first data analysis program at NASA and generated new funds for basic research starting in 1976. This new program contributed to a 26% jump in abstract submissions in 1978 (the ninth LPSC) from the previous year. While DPS and the PGPI meetings continued, LPSC was now the place to present the latest results and hypotheses about the compositions of the planets and the contrasting processes shaping their surfaces. Abstract submissions would remain between 445 and 490 for the next eight years.

For me, LPSC was about more than just giving and attending science presentations. My wife and I would regularly entertain as many as 15–20 visitors at our house for hors d'oeuvres. During one meeting, I arrived home a bit early to find my wife on top of the counter, scraping off food from the ceiling, while our guests arrived just a few minutes behind me. She had left a wooden spoon in the mixer that ballistically launched her cheese dip. There was a change in domestic procedures after that (including instructions to call ahead).

The era of Willy Nelson and Mickey Gilley led to the famous (infamous?) LPSC Chili Cook-Off in 1981, first held on the LPI grounds and later at the Landolt Pavilion in a nearby park across from Clear Lake. There were some classic chili recipes, which I will just say were rather “interesting”; venison,
Conference attendees were given a “Taste of Texas” at the chili cook-off and barbecue dinner at the Pasadena Fairgrounds in 1993. Credit: Lunar and Planetary Institute.


There were only a handful of planetary missions during the 1980s, not counting every planet encountered by Voyager, which flew by Neptune in 1989, and the flotilla of non-U.S. missions to Comet Halley. The Challenger disaster in 1986 delayed several planned missions and put fiscal pressures on other programs. Nevertheless, LPSC remained a vibrant meeting because of new discoveries, including the global iridium layer at the K/T (K/Pg) boundary and the recognition of meteorites from Mars. As a result, I recall being in one of the Mars sessions in one of the small rooms in the Gilruth Center where only 20 people attended. In other years, only 15 people attended a session about the Moon. By 1981 (the twelfth LPSC), all oral sessions were held in the Gilruth Center.

After moving to Brown University in 1984, I no longer had the luxury of simply slipping my abstract under the door of the Publications Department on the day of the abstract deadline. Now, abstract-deadline day became an annual stressor. I would have to send any abstracts to Houston the day before. My students will confirm that we literally jogged down the hill to the downtown FedEx Office, sometimes with only minutes to spare. A couple of times, there was a car waiting outside to drive to the FedEx Center (near the airport), which stayed open later. One year, I actually flew down and delivered my abstracts in person. (While this sounds like a great story, the trip actually coincided with the dedication of the new USRA/LPI building in 1992.)

In the 1980s, hotels in the vicinity of NASA JSC began to decline. But I thought it was important to give my students a sense of history by continuing to stay in the “Nausea” Bay Hotel. However, by 1986, there were only a few floors open in the hotel, and the Boom-Boom Room had closed. The “sense” of history (and the name “Nausea Bay”) became literal when sewage came up through the tub drain in one of our rooms. The following year, we chose a different hotel (and the Nassau Bay Hotel was demolished a few years later).

Until 1991, the Planetary Geology Program still required its funded investigators to attend the PGPI meetings. In the beginning, their presentations actually contributed to their Progress Reports, somewhat similar to the very first Apollo 11 Lunar Science Conference. This program covered a broad range of disciplines, from the solar system formation to planetary mapping (and eventually was renamed to the Planetary Geology and Geophysics Program, or PGGPI). By the early 1990s, the line between topics in the PGGPI and LPSC meetings had blurred. As the PGGPI meetings ended, there was another surge in LPSC abstracts between 1990 and 1991, strengthening the role of the Houston conference as the key meeting where new findings about the planets, as well as the Moon, were presented.

In the early 1990s, striking new images of the surface of Venus resulted from the Magellan mission, and in the mid-1990s the Clementine mission...
returned new remote-sensing data about the Moon. But the number of abstract submissions remained relative constant (700–800) until 1999. In 1998, Lunar Prospector was launched, the Mars Global Surveyor first orbited Mars, and both Mars Pathfinder and Galileo mission (Galilean satellites) results were being reported. As a result, the 30th LPSC in 1999 featured a large increase in the number of abstracts (from 823 to 1075).

Until about 2002, most presentations used slide projectors or viewgraph projectors, eventually with dual screens. Some government presenters preferred viewgraphs because they were easier to create and display. In the large gyms, black curtains surrounded the platform with the slide projectors like a scene from the Wizard of Oz. We all have stories of upside down or reverse slides, projectors that stuck, and blown bulbs that reduced our talks from 10 minutes to 5. During the transition from slides to digital presentations, I noticed that the power of the projectors dropped precipitously (and not because of the contrast between the old and new media). I suspect they used lower-wattage bulbs as a not-so subtle way to encourage luddites to make the transition. I finally did.

In 2002, LPSC moved to the South Shore Harbor Hotel in League City largely in response to security concerns after the September 11 attack the previous year. [Editor's note: Security increased substantially at all NASA centers, and it was not clear whether the Gilruth Center would remain inside or outside the gates.] This move still allowed satellite meetings either at the hotel, at the LPI, or even at NASA JSC before or after the meeting. In addition, attendees still could make visits to the NASA Visitor Center. But after 7 years, this venue also became too small, and in 2009 LPSC moved to The Woodlands (north of Houston) for the 40th LPSC. Even though this venue was much farther away from NASA JSC, many researchers and students still headed down to the LPI or NASA JSC before and after the meetings.

The new millennium ushered in a flood of new data from both NASA and foreign missions (Mars Odyssey, Spirit/Oportunity, Mars Express, Rosetta, MESSENGER, Deep Impact, Mars Reconnaissance Orbiter, Phoenix, Kaguya, Dawn, Lunar Reconnaissance Orbiter, Chandrayaan-1, and LCROSS). By the end of the decade, the 41st LPSC had more than 1800 abstract submissions. These were the golden years of planetary exploration and discovery reflected in the flood of abstracts, which increased from 1100 at the 31st LPSC in 2000 to over 1800 at the 42nd LPSC in 2011. By the 44th LPSC, this number increased to over 2000, a level maintained at the 49th LPSC. Anyone with a broad interest had difficulty in deciding which session to attend. [Editor's note: In spite of the partial government shutdown in the U.S., this year's 50th LPSC garnered a record number of abstract submissions: 2282.]

From the very beginning, the LSI/LPI arranged for the Galveston Limousine Service to shuttle conference goers between the LPSC venue and their hotels. Dominic Noto, who owned the service, is now one of the six remaining people who have been at all 50 meetings. Even after retiring and selling his service, Dominic still comes to the meeting and greets LPSC goers, simply because it is part of his legacy as well. If you see him at this year's conference, give him a "high-five."

This is my own reflection about the history of the Lunar and Planetary Science Conferences. I suspect that others would focus on different areas (e.g., the Hawaii or Arizona parties), and it would be great to hear their perspectives. The LPSC continues to include the latest results about planetary exploration while including fundamental research in lunar/planetary geology, exoplanets, exobiology, future mission planning, education, and public engagement with over 2000 abstract submissions from researchers around the world in 2018. What had started with coverage of just the Moon has now expanded to cover the entire solar system and beyond. This year marks my 50th conference, and I have to be there, just to be blown away by the latest results, whether from a mission or new interpretations of old data. Several years ago, I was not sure if I’d make it to the meeting (things happen). In the worst-case scenario, I asked my students to spread my ashes across certain seats at the 50th LPSC, just to leave my mark “behind.” Rest assured that I’ll be there one way or the other.
One of the most highly attended LPSC special sessions was the Mars session in 2004, at which science results from Mars Exploration Rovers Spirit and Opportunity were presented for the first time. Not only was every available chair taken, but attendees sat on the floor by the projection screen, stood along the walls in the front and back of the room, and stood outside the doors, straining to hear the talks. Credit: Lunar and Planetary Institute.

The Lunar and Planetary Information Bulletin collects, synthesizes, and disseminates current research and findings in the planetary sciences to the research community, science libraries, educators, students, and the public. The Bulletin is dedicated to engaging, exciting, and educating those with a passion for the space sciences while developing future generations of explorers.

The Bulletin welcomes articles dealing with issues related to planetary science and exploration. Of special interest are articles describing web-based research and educational tools, meeting highlights and summaries, and descriptions of space missions. Peer-reviewed research articles, however, are not appropriate for publication in the Bulletin. Suggested topics can be e-mailed to the editors, who will provide guidelines for formatting and content.

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“That’s one small step for [a] man, one giant leap for mankind.” Words said when Neil Armstrong first stepped onto the Moon. These words shaped my generation and catapulted the field of planetary science to a new era. On July 20, 1969, Armstrong and Edwin “Buzz” Aldrin became the first men to walk on the Moon. NASA’s Planetary Science Division is preparing for a year of anniversaries in 2019 that not only celebrate our history and progress in human exploration, but also the science that was enabled by the exploration of space.

Following the successful Mariner 2 flyby of Venus in 1962 and the historic Moon landing of 1969, our community of planetary scientists needed a venue for communicating their findings and interacting with their peers. On March 12, 1969, the Universities Space Research Association was incorporated under an agreement between the National Academy of Science and NASA. That same year, Mariner 6 returned images from Mars. On December 11, 1969, the Universities Space Research Association took over the management of the nascent Lunar Science Institute (LSI), and shortly thereafter the first lunar symposium was organized. The first LSI symposium, “Geophysical Interpretation of the Moon,” was the initial meeting of 15 scientists for the explicit purpose of interpreting the existing data on the geophysics of the Moon. The LSI Seminar Series was established with Gerard P. Kuiper as the first featured speaker. The first Lunar Science Conference, known as the Apollo 11 Lunar Science Conference, was held in Houston on January 5–8, 1970. This historical event marked the first time we, as a community, discussed the first findings from the lunar samples. The next year Mariner 9 was the first spacecraft to orbit Mars, providing data of the entire martian surface. Apollo 14 collected even more lunar samples. Since then, we have continuously launched missions that have provided a community of scientists with data from each of the planets and some of the moons of the solar system.

In 1978, the name of the conference was changed from the Lunar Science Conference to the Lunar and Planetary Science Conference (LPSC). And the rest — as they say — is, indeed, history! The years passed and as more planets were visited and studied, LPSC grew. Mariner 10 provided the first views of Mercury; the Pioneer missions brought us closer to Venus, Jupiter, and Saturn; and the two Voyager spacecraft conducted a grand tour of the solar system. And because science is not done alone, our international colleagues joined us. In fact, participation in the 1974 “Lunar Geology Conference” included 132 international attendees, NASA Headquarters, other NASA centers, other government agencies (both U.S. and foreign), and universities.

In a sense LPSC and planetary science at NASA grew together. Since its inception, LPSC was connected to research of the Apollo program lunar samples and the culmination of discussions between NASA and academia. Since then, every year, seminal planetary science research and NASA missions have been ever-present topics of the LPSC.

I have been attending the LPSC every year since the 25th meeting in 1994. I recall my first presentation in the JSC Gilruth Center using viewgraphs and an overhead projector: “A Theoretical Study of SO\textsubscript{2} Transport by Explosive Volcanism on Venus.” I believe the audience consisted of about 20 people and the conversation was effervescent, providing paths to new collaborations and partnerships. The whole conference’s ambience was exciting and had a sense of family. The ice breakers kicked off the conference and facilitated communications between diverse groups of scientists that covered various disciplines.

Beyond the science, some of my fondest early memories of LPSC when it was held in Clear Lake, and later in League City, were the LPSC Chili Cookoffs. These events provided a great opportunity to develop friendships and collaborations in a social setting. The camaraderie and conversations sealed my already strong commitment to planetary science. In a sense, that was the impact the LPSC had on all of us. Finally, the planetary science community had a place that would cover all of its disciplines and provide scientists from diverse fields a platform to meet regularly and discuss findings and future plans. This is a place where geologists, chemists, planetary astronomers, dynamists, heliophysicists, atmospheric physicists, and microbiologists focus on one subject: the solar system with its planets and moons.

For the past 50 years, the primary goal of NASA’s Planetary Science Division has always focused on advancing our scientific knowledge of the origin and evolution of the solar system, the potential for life elsewhere, and safeguarding and improving life on Earth.

In 2019, LPSC will continue to regale us with the latest planetary science results and discoveries, reflecting on all the incredible planetary science events of 2018. As an international planetary science community, we have successfully launched and landed the InSight mission to Mars. JAXA’s Hayabusa2 arrived at asteroid Ryugu, deployed the MASCOT lander, and MINERVA-I1I touched down on Ryugu. OSIRIS-REx successfully arrived at its rendezvous with Bennu, and in December, began its orbit around the asteroid and sent us breathtakingly detailed data for a near-Earth object with tantalizing surface material to be sampled and brought back to Earth. In October, the European Space Agency successfully launched the BepiColombo missions to Mercury. And the year ended with a celebratory flyby of Ultima Thule by the New Horizons spacecraft, providing us with an unprecedented look at a primordial piece of our solar system preserved in the Kuiper belt.

As we look forward to the future and the planetary missions that will provide new observations that enable us discover more about how our solar system formed and evolved, I look forward to learning about these discoveries at our annual gatherings. I would like to congratulate the LPSC on 50 fantastic years and look forward to many more amazing science mysteries to be revealed each year going forward. Science never sleeps, and I cannot imagine our field without the LPSC or the LPSC without our field! — Lori S. Glaze, Acting Director, NASA’s Planetary Science Division, January 2019
China's Chang'e-4 Probe Lands on the Moon's Far Side

The China National Space Administration made history on January 3, when the Chang'e-4 spacecraft became the first to make a soft landing on the lunar farside. Chang'e-4 touched down in Von Kármán crater, located within the immense South Pole-Aitken basin, becoming the first spacecraft to visit the oldest impact basin on the Moon.

As direct communications between Chang'e-4 and Earth are not possible from the lunar farside, the lander relays its data to Earth via CNSA's new Queqiao communications satellite, which was launched in May 2018.

Chang'e-4 and Yutu-2 have diverse scientific payloads, including lunar ground penetrating radar, a visible and near infrared imaging system, a sealed miniature biosphere containing silkworm larvae and several types of plant seeds, and a Swedish instrument designed to study how solar wind interacts with the lunar surface.

The Yutu-2 rover successfully drives onto the lunar surface from China's Chang'e-4 lander, which became the first spacecraft to make a soft landing on the lunar farside on January 3. Credit: CNSA/CGTN Twitter.
Recently analyzed data from NASA’s Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission has revealed water locked inside the clays that make up its scientific target, the asteroid Bennu.

During the mission’s approach phase, between mid-August and early December, the spacecraft traveled 2.2 million kilometers (1.4 million miles) on its journey from Earth to arrive at a location 19 kilometers (12 miles) from Bennu on December 3. During this time, the science team on Earth aimed three of the spacecraft’s instruments towards Bennu and began making the mission’s first scientific observations of the asteroid. OSIRIS-REx is NASA’s first asteroid sample return mission.

Data obtained from the spacecraft’s two spectrometers, the OSIRIS-REx Visible and Infrared Spectrometer (OVIRS) and the OSIRIS-REx Thermal Emission Spectrometer (OTES), reveal the presence of molecules that contain oxygen and hydrogen atoms bonded together, known as “hydroxyls.” The team suspects that these hydroxyl groups exist globally across the asteroid in water-bearing clay minerals, meaning that at some point, Bennu’s rocky material interacted with water. While Bennu itself is too small to have ever hosted liquid water, the finding does indicate that liquid water was present at some time on Bennu’s parent body, a much larger asteroid.

“The presence of hydrated minerals across the asteroid confirms that Bennu, a remnant from early in the formation of the solar system, is an excellent specimen for the OSIRIS-REx mission to study the composition of primitive volatiles and organics,” said Amy Simon, OVIRS deputy instrument scientist at NASA’s Goddard Space Flight Center in Greenbelt, Maryland. “When samples of this material are returned by the mission to Earth in 2023, scientists will receive a treasure trove of new information about the history and evolution of our solar system.”

Additionally, data obtained from the OSIRIS-REx Camera Suite (OCAMS) corroborate ground-based telescopic observations of Bennu and confirm the original model developed in 2013 by OSIRIS-REx Science Team Chief Michael Nolan and collaborators. That model closely predicted the asteroid’s actual shape, with Bennu’s diameter, rotation rate, inclination, and overall shape presented almost exactly as projected.
One outlier from the predicted shape model is the size of the large boulder near Bennu's south pole. The ground-based shape model calculated this boulder to be at least 10 meters (33 feet) in height. Preliminary calculations from OCAMS observations show that the boulder is closer to 50 meters (164 feet) in height, with a width of approximately 55 meters (180 feet).

Bennu's surface material is a mix of very rocky, boulder-filled regions and a few relatively smooth regions that lack boulders. However, the quantity of boulders on the surface is higher than expected. The team will make further observations at closer ranges to more accurately assess where a sample can be taken on Bennu to be returned to Earth later.

“Our initial data show that the team picked the right asteroid as the target of the OSIRIS-REx mission. We have not discovered any insurmountable issues at Bennu so far,” said Dante Lauretta, OSIRIS-REx principal investigator at the University of Arizona, Tucson. “The spacecraft is healthy and the science instruments are working better than required. It is time now for our adventure to begin.”

The mission currently is performing a preliminary survey of the asteroid, flying the spacecraft in passes over Bennu’s north pole, equator, and south pole at ranges as close as 7 kilometers (4.4 miles) to better determine the asteroid’s mass. The mission’s scientists and engineers must know the mass of the asteroid in order to design the spacecraft’s insertion into orbit because mass affects the asteroid’s gravitational pull on the spacecraft. Knowing Bennu’s mass will also help the science team understand the asteroid’s structure and composition.

This survey also provides the first opportunity for the OSIRIS-REx Laser Altimeter (OLA), an instrument contributed by the Canadian Space Agency, to make observations now that the spacecraft is in proximity to Bennu.

The spacecraft’s first orbital insertion was scheduled for December 31, and OSIRIS-REx will remain in orbit until mid-February 2019, when it exits to initiate another series of flybys for the next survey phase. During the first orbital phase, the spacecraft will orbit the asteroid at a range of 1.4 kilometers (0.9 miles) to 2.0 kilometers (1.24 miles) from the center of Bennu — setting new records for the smallest body ever orbited by a spacecraft and the closest orbit of a planetary body by any spacecraft.

Goddard provides overall mission management, systems engineering and the safety and mission assurance for OSIRIS-REx. Dante Lauretta of the University of Arizona, Tucson, is the principal investigator, and the University of Arizona also leads the science team and the mission’s science observation planning and data processing. Lockheed Martin Space Systems in Denver built the spacecraft and is providing flight operations. Goddard and KinetX Aerospace are responsible for navigating the OSIRIS-REx spacecraft. OSIRIS-REx is the third mission in NASA’s New Frontiers Program. NASA’s Marshall Space Flight Center in Huntsville, Alabama, manages the agency’s New Frontiers Program for the Science Mission Directorate in Washington.

For more information about OSIRIS-REx, visit https://www.nasa.gov/osiris-rex.

**NASA’s New Horizons Mission Reveals Entirely New Kind of World**

The first color image of Ultima Thule, taken at a distance of 137,000 kilometers (85,000 miles) at 4:08 Universal Time on January 1, 2019, highlights its reddish surface. Left is an enhanced color image taken by the Multispectral Visible Imaging Camera (MVIC), produced by combining the near-infrared, red, and blue channels. The center image taken by the Long-Range Reconnaissance Imager (LORRI) has a higher spatial resolution than MVIC by approximately a factor of 5. At right, the color has been overlaid onto the LORRI image to show the color uniformity of the Ultima and Thule lobes. Credit: NASA/JHU-APL/Southwest Research Institute.

Scientists from NASA’s New Horizons mission released the first detailed images of the most distant object ever explored — the Kuiper belt object nicknamed Ultima Thule. Its remarkable appearance, unlike anything we’ve seen before, illuminates the processes that built the planets 4.5 billion years ago. “This flyby is a historic achievement,” said New Horizons Principal Investigator Alan Stern of the Southwest Research Institute in Boulder, Colorado. “Never before has any spacecraft team tracked down such a small body at such high speed so far away in the abyss of space. New Horizons has set a new bar for state-of-the-art spacecraft navigation.”
The new images — taken from as close as 27,000 kilometers (17,000 miles) on approach — revealed Ultima Thule as a “contact binary,” consisting of two connected spheres. End to end, the world measures 31 kilometers (19 miles) in length. The team has dubbed the larger sphere “Ultima” (19 kilometers/12 miles across) and the smaller sphere “Thule” (14 kilometers/9 miles across).

The team says that the two spheres likely joined as early as 99% of the way back to the formation of the solar system, colliding no faster than two cars in a fender-bender.

“New Horizons is like a time machine, taking us back to the birth of the solar system. We are seeing a physical representation of the beginning of planetary formation, frozen in time,” said Jeff Moore, New Horizons Geology and Geophysics team lead. “Studying Ultima Thule is helping us understand how planets form — both those in our own solar system and those orbiting other stars in our galaxy.”

Data from the New Year’s Day flyby will continue to arrive over the next weeks and months, with much higher resolution images yet to come.

“In the coming months, New Horizons will transmit dozens of data sets to Earth, and we’ll write new chapters in the story of Ultima Thule — and the solar system,” said Helene Winters, New Horizons Project Manager.

For the latest on New Horizons and Ultima Thule, visit http://pluto.jhuapl.edu.

**NASA Announces Landing Site for Mars 2020 Rover**

On ancient Mars, water carved channels and transported sediments to form fans and deltas within lake basins. Examination of spectral data acquired from orbit show that some of these sediments have minerals that indicate chemical alteration by water. Here in Jezero Crater delta, sediments contain clays and carbonates. The image combines information from two instruments on NASA’s Mars Reconnaissance Orbiter, the Compact Reconnaissance Imaging Spectrometer for Mars and the Context Camera. Credit: NASA/JPL-Caltech/MSSS/JHU-APL.

NASA has chosen Jezero Crater as the landing site for its upcoming Mars 2020 rover mission after a five-year search, during which details of more than 60 candidate locations on the red planet were scrutinized and debated by the mission team and the planetary science community.

The rover mission is scheduled to launch in July 2020 as NASA’s next step in exploration of the red planet. It will not only seek signs of ancient habitable conditions and past microbial life, but the rover also will collect rock and soil samples and store them in a cache on the planet’s surface. NASA and ESA (European Space Agency) are studying future mission concepts to retrieve the samples and return them to Earth, so this landing site...
sets the stage for the next decade of Mars exploration.

“The landing site in Jezero Crater offers geologically rich terrain, with landforms reaching as far back as 3.6 billion years old, that could potentially answer important questions in planetary evolution and astrobiology,” said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate. “Getting samples from this unique area will revolutionize how we think about Mars and its ability to harbor life.”

Jezero Crater is located on the western edge of Isidis Planitia, a giant impact basin just north of the Martian equator. Western Isidis presents some of the oldest and most scientifically interesting landscapes Mars has to offer. Mission scientists believe the 45-kilometer-wide (28-mile-wide) crater, once home to an ancient river delta, could have collected and preserved ancient organic molecules and other potential signs of microbial life from the water and sediments that flowed into the crater billions of years ago.

Jezero Crater's ancient lake-delta system offers many promising sampling targets of at least five kinds of rock, including clays and carbonates that have high potential to preserve signatures of past life. In addition, the material carried into the delta from a large watershed may contain a wide variety of minerals from inside and outside the crater.

The geologic diversity that makes Jezero so appealing to Mars 2020 scientists also makes it a challenge for the team's entry, descent and landing (EDL) engineers. Along with the massive nearby river delta and small crater impacts, the site contains numerous boulders and rocks to the east, cliffs to the west, and depressions filled with aeolian bedforms (wind-derived ripples in sand that could trap a rover) in several locations.

“The Mars community has long coveted the scientific value of sites such as Jezero Crater, and a previous mission contemplated going there, but the challenges with safely landing were considered prohibitive,” said Ken Farley, project scientist for Mars 2020 at NASA's Jet Propulsion Laboratory in Pasadena, California. “But what was once out of reach is now conceivable, thanks to the 2020 engineering team and advances in Mars entry, descent and landing technologies.”

When the landing site search began, mission engineers already had refined the landing system such that they were able to reduce the Mars 2020 landing zone to an area 50% smaller than that for the landing of NASA's Curiosity rover at Gale Crater in 2012. This allowed the science community to consider more challenging landing sites. The sites of greatest scientific interest led NASA to add a new capability called Terrain Relative Navigation (TRN). TRN will enable the “sky crane” descent stage, the rocket-powered system that carries the rover down to the surface, to avoid hazardous areas.

The site selection is dependent upon extensive analyses and verification testing of the TRN capability. A final report will be presented to an independent review board and NASA Headquarters in the fall of 2019.

“Nothing has been more difficult in robotic planetary exploration than landing on Mars,” said Zurbuchen. “The Mars 2020 engineering team has done a tremendous amount of work to prepare us for this decision. The team will continue its work to truly understand the TRN system and the risks involved, and we will review the findings independently to reassure we have maximized our chances for success.”

Selecting a landing site this early allows the rover drivers and science operations team to optimize their plans for exploring Jezero Crater once the rover is safely on the ground. Using data from NASA's fleet of Mars orbiters, they will map the terrain in greater detail and identify regions of interest — places with the most interesting geological features, for example — where Mars 2020 could collect the best science samples.

New NASA research confirms that Saturn is losing its iconic rings at the maximum rate estimated from Voyager 1 and 2 observations made decades ago. The rings are being pulled into Saturn by gravity as a dusty rain of ice particles under the influence of Saturn's magnetic field.

"We estimate that this 'ring rain' drains an amount of water products that could fill an Olympic-sized swimming pool from Saturn's rings in half an hour," said James O'Donoghue of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "From this alone, the entire ring system will be gone in 300 million years, but add to this the Cassini-spacecraft measured ring-material detected falling into Saturn's equator, and the rings have less than 100 million years to live. This is relatively short, compared to Saturn's age of over 4 billion years." O'Donoghue is lead author of a study on Saturn's ring rain that recently appeared in Icarus.

Scientists have long wondered if Saturn was formed with the rings or if the planet acquired them later in life. The new research favors the latter scenario, indicating that they are unlikely to be older than 100 million years, as it would take that long for the C-ring to become what it is today assuming it was once as dense as the B-ring. "We are lucky to be around to see Saturn's ring system, which appears to be in the middle of its lifetime. However, if rings are temporary, perhaps we just missed out on seeing giant ring systems of Jupiter, Uranus and Neptune, which have only thin ringlets today!" O'Donoghue added.

Various theories have been proposed for the origin of the rings. If the planet got them later in life, the rings could have formed when small, icy moons in orbit around Saturn collided, perhaps because their orbits were perturbed by a gravitational tug from a passing asteroid or comet.

The first hints that ring rain existed came from Voyager observations of seemingly unrelated phenomena: peculiar variations in Saturn's electrically charged upper atmosphere (ionosphere), density variations in Saturn's rings, and a trio of narrow dark bands encircling the planet at northern mid-latitudes. These dark bands appeared in images of Saturn's hazy upper atmosphere (stratosphere) made by NASA's Voyager 2 mission in 1981.

In 1986, Jack Connerney of NASA Goddard published a paper in Geophysical Research Letters that linked those narrow dark bands to the shape of Saturn's enormous magnetic field, proposing that electrically charged ice particles from Saturn's rings were flowing down invisible magnetic field lines, dumping water in Saturn's upper atmosphere where these lines emerged from the planet. The influx of water from the rings, appearing at specific latitudes, washed away the stratospheric haze, making it appear dark in reflected light, producing the narrow dark bands captured in the Voyager images.

Saturn's rings are mostly chunks of water ice ranging in size from microscopic dust grains to boulders several meters (yards) across. Ring particles are caught in a balancing act between the pull of Saturn's gravity, which wants to draw them back into the planet, and their orbital velocity, which wants to fling them outward into space. Tiny particles can get electrically charged by ultraviolet light from the Sun or by plasma clouds emanating from micrometeoroid bombardment of the rings. When this happens, the particles can feel the pull of Saturn's magnetic field, which curves inward toward the planet at Saturn's rings. In some parts of the rings, once charged, the balance of forces on these tiny particles changes dramatically, and Saturn's gravity pulls them in along the magnetic field lines into the upper atmosphere.
Once there, the icy ring particles vaporize, and the water can react chemically with Saturn's ionosphere. One outcome from these reactions is an increase in the lifespan of electrically charged particles called H3+ ions, which are made up of three protons and two electrons. When energized by sunlight, the H3+ ions glow in infrared light, which was observed by O'Donoghue's team using special instruments attached to the Keck telescope in Mauna Kea, Hawaii.

Their observations revealed glowing bands in Saturn's northern and southern hemispheres where the magnetic field lines that intersect the ring plane enter the planet. They analyzed the light to determine the amount of rain from the ring and its effects on Saturn's ionosphere. They found that the amount of rain matches remarkably well with the astonishingly high values derived more than three decades earlier by Connerney and colleagues, with one region in the south receiving most of it.

The team also discovered a glowing band at a higher latitude in the southern hemisphere. This is where Saturn's magnetic field intersects the orbit of Enceladus, a geologically active moon that is shooting geysers of water ice into space, indicating that some of those particles are raining onto Saturn as well. “That wasn't a complete surprise,” said Connerney. “We identified Enceladus and the E-ring as a copious source of water as well, based on another narrow dark band in that old Voyager image.” The geysers, first observed by Cassini instruments in 2005, are thought to be coming from an ocean of liquid water beneath the frozen surface of the tiny moon. Its geologic activity and water ocean make Enceladus one of the most promising places to search for extraterrestrial life.

The team would like to see how the ring rain changes with the seasons on Saturn. As the planet progresses in its 29.4-year orbit, the rings are exposed to the Sun to varying degrees. Since ultraviolet light from the Sun charges the ice grains and makes them respond to Saturn's magnetic field, varying exposure to sunlight should change the quantity of ring rain.


**NASA Learns More About Interstellar Visitor ‘Oumuamua**

An artist's concept of interstellar asteroid 1I/2017 U1 (‘Oumuamua) as it passed through the solar system after its discovery in October 2017. Observations of ‘Oumuamua indicate that it must be very elongated because of its dramatic variations in brightness as it tumbled through space. Credit: European Southern Observatory/M. Kornmesser.

In November 2017, scientists pointed NASA's Spitzer Space Telescope toward the object known as ‘Oumuamua — the first known interstellar object to visit our solar system. The infrared Spitzer was one of many telescopes pointed at ‘Oumuamua in the weeks after its discovery that October.

‘Oumuamua was too faint for Spitzer to detect when it looked more than two months after the object's closest approach to Earth in early September. However, the "non-detection" puts a new limit on how large the strange object can be. The results are reported in a recent study published in the Astronomical Journal.

The new size limit is consistent with the findings of a research paper published earlier this year, which suggested that outgassing was responsible for the slight changes in ‘Oumuamua's speed and direction as it was tracked last year: The authors of that paper conclude the expelled gas acted like a small thruster gently pushing the object. That determination was dependent on ‘Oumuamua being relatively smaller than typical solar system comets.
(The conclusion that ‘Oumuamua experienced outgassing suggested that it was composed of frozen gases, similar to a comet.)

“‘Oumuamua has been full of surprises from day one, so we were eager to see what Spitzer might show,” said David Trilling, lead author on the recent study and a professor of astronomy at Northern Arizona University. “The fact that ‘Oumuamua was too small for Spitzer to detect is actually a very valuable result.”

‘Oumuamua was first detected by the University of Hawaii's Pan-STARRS 1 telescope on Haleakala, Hawaii (the object's name is a Hawaiian word meaning “visitor from afar arriving first”), in October 2017 while the telescope was surveying for near-Earth asteroids.

Subsequent detailed observations conducted by multiple ground-based telescopes and NASA's Hubble Space Telescope detected the sunlight reflected off ‘Oumuamua's surface. Large variations in the object's brightness suggested that ‘Oumuamua is highly elongated and probably less than half a mile (800 meters, or 2,600 feet) in its longest dimension.

But Spitzer tracks asteroids and comets using the infrared energy, or heat, that they radiate, which can provide more specific information about an object's size than optical observations of reflected sunlight alone would.

The fact that ‘Oumuamua was too faint for Spitzer to detect sets a limit on the object's total surface area. However, since the non-detection can't be used to infer shape, the size limits are presented as what ‘Oumuamua's diameter would be if it were spherical. Using three separate models that make slightly different assumptions about the object's composition, Spitzer's non-detection limited ‘Oumuamua's “spherical diameter” to 440 meters (1,440 feet), 140 meters (460 feet) or perhaps as little as 100 meters (320 feet). The wide range of results stems from the assumptions about ‘Oumuamua's composition, which influences how visible (or faint) it would appear to Spitzer were it a particular size.

The new study also suggests that ‘Oumuamua may be up to 10 times more reflective than the comets that reside in our solar system — a surprising result, according to the paper's authors. Because infrared light is largely heat radiation produced by “warm” objects, it can be used to determine the temperature of a comet or asteroid; in turn, this can be used to determine the reflectivity of the object's surface — what scientists call albedo. Just as a dark T-shirt in sunlight heats up more quickly than a light one, an object with low reflectivity retains more heat than an object with high reflectivity. So a lower temperature means a higher albedo.

A comet's albedo can change throughout its lifetime. When it passes close to the Sun, a comet’s ice warms and turns directly into a gas, sweeping dust and dirt off the comet's surface and revealing more reflective ice.

‘Oumuamua had been traveling through interstellar space for millions of years, far from any star that could refresh its surface. But it may have had its surface refreshed through such “outgassing” when it made an extremely close approach to our Sun, a little more than five weeks before it was discovered. In addition to sweeping away dust and dirt, some of the released gas may have covered the surface of ‘Oumuamua with a reflective coat of ice and snow — a phenomenon that's also been observed in comets in our solar system.

‘Oumuamua is on its way out of our solar system — almost as far from the Sun as Saturn's orbit — and is well beyond the reach of any existing telescopes.

“Usually, if we get a measurement from a comet that's kind of weird, we go back and measure it again until we understand what we're seeing,” said Davide Farnocchia, of the Center for Near Earth Object Studies (CNEOS) at JPL and a coauthor on both papers. "But this one is gone forever; we probably know as much about it as we're ever going to know."

For more information about interstellar asteroids, visit https://www.nasa.gov/planetarydefense/faq/interstellar.

The Camera That Saved Hubble Turns 25

Twenty-five years ago, NASA held its collective breath as seven astronauts on space shuttle Endeavour caught up with the Hubble Space Telescope 568 kilometers (353 miles) above Earth. Their mission: to fix a devastating flaw in the telescope's primary mirror.

About the size of a school bus, the Hubble Space Telescope has a 2.4-meter (8-foot) primary mirror. The largest optical telescope ever launched into space, where it could observe the universe free from the distorting effects of Earth's atmosphere, Hubble had a lot riding on it. But after the first images were obtained and carefully analyzed following the telescope's deployment on April 25, 1990, it was clear that something was wrong: The images were blurry.

Astronomers and engineers rallied to study a variety of solutions to the problem, and NASA
Complicating matters further was the weight of WFPC2: At more than 272 kilograms (600 pounds), it was unwieldy even in the microgravity of low-

body, as if sliding it in a drawer. And although they would need to make sure that the electrical connections at the back of the instrument were secure, they had no way of reaching those connections; they could control only how they inserted the instrument.

To minimize the chance for error during WFPC2's installation in low-Earth orbit, the seven astronauts who were scheduled to execute the repair mission traveled to JPL to learn about the instrument and be trained on how to install it. They would be inserting WFPC2 into a cavity in the telescope's


world, as if sliding it in a drawer. And although they would need to make sure that the electrical connections at the back of the instrument were secure, they had no way of reaching those connections; they could control only how they inserted the instrument.

The second instrument was the Wide Field and Planetary Camera 2 (WFPC2), designed and built at NASA's Jet Propulsion Laboratory in Pasadena, California. WFPC2, which actually contains four cameras, would go on to produce many of Hubble's breathtaking images, helping transform our view of the cosmos.

The size of baby grand piano, the instrument imaged objects and events that occurred in our own solar system — such as comet Shoemaker-Levy 9's

crash into Jupiter — to the most distant cosmological images that had ever been taken in visible light. It generated breathtaking snapshots of galaxies, exploded stars and nebulae where new stars are born. During the instrument's tenure, Hubble managers pointed the telescope at a single, black

patch of sky for more than a week and found thousands of previously unseen galaxies.

But WFPC2's success was far from guaranteed. The instrument was built on an incredibly tight timeline, and designing it to correct the flaw was something JPL's John Trauger, principal investigator for WFPC2, would later describe as being akin to "trying to play baseball on the side of a hill."

"There's a lot of pressure when you're building a space instrument even under normal circumstances," said Dave Gallagher, JPL's associate director for strategic integration, who served as integration and test manager for WFPC2. "But when you're fixing something that will essentially make or break the reputation of the entire agency, the pressure goes through the roof."

In June 1990, NASA announced that the Hubble telescope was not working as expected. WFPC2 team members say they remember that the reaction from the public and the media was often pessimistic or even incredulous. Trauger watched network news anchor Tom Brokaw begin his program that evening by saying, "The Hubble Telescope you've heard so much about — it's broken."

"The promise of the Hubble program, the application of our best technology to push back the frontiers of astronomy, had been instantly transformed in the public eye to an icon of technical failure," Trauger wrote in an essay in 2007.

Trauger brought his team together to work the problem. The telescope's primary and secondary mirrors collected light and fed it to the five onboard science instruments. The primary mirror could not be replaced and could not be returned to Earth for repairs. A solution would have to be found for each of Hubble's instruments. The COSTAR device provided corrective optics for three of them, eliminating the need to fully replace those instruments. But the same approach wouldn't work for the telescope's Wide Field and Planetary Camera (WFPC), the predecessor of WFPC2.

Trauger and his team came up with a potential solution. The primary mirror error caused light striking different parts of the mirror to come into focus at different locations, so the team had to figure out how to redirect it to the appropriate focal point. Their solution was to reverse-engineer the problem: They would place four identical nickel-sized mirrors inside the instrument — one for each of the four cameras inside WFPC2 — with the same error as the flawed primary mirror, but where the primary mirror was too flat, the new mirrors would be curved too deeply. Together, these two errors would cancel each other, producing the equivalent of a single mirror with the correct shape.

NASA accepted JPL's proposal to build a WFPC replacement. The agency had planned to carry out Hubble repair missions every three years and decided to maintain this schedule. The first repair mission was set for the fall of 1993. JPL would need to deliver the replacement by the winter of 1992 — just over 2 years away. The race to repair Hubble was on.

Two years was nowhere near enough time to build a new camera instrument from scratch. Thankfully, WFPC2 was already under construction at JPL; NASA had intended to eventually use it as an upgrade for WFPC or a replacement if the instrument ever failed.

Even with work on WFPC2 already under way, the deadline required an accelerated schedule. Dave Rodgers and Larry Simmons, the WFPC2 project managers, held daily meetings with the leaders of each of WFPC2's several components to help stay on target.

"The daily meetings kept the pressure on all of us, all the time," said Simmons, who retired from JPL in 2005. "We knew we only had a few years, and we had to get it done."

While the corrective mirrors were small, they affected nearly every step of the building process and created "an endless string of novel problems," according to Trauger.

To minimize the chance for error during WFPC2's installation in low-Earth orbit, the seven astronauts who were scheduled to execute the repair mission traveled to JPL to learn about the instrument and be trained on how to install it. They would be inserting WFPC2 into a cavity in the telescope's body, as if sliding it in a drawer. And although they would need to make sure that the electrical connections at the back of the instrument were secure, they had no way of reaching those connections; they could control only how they inserted the instrument.

Complicating matters further was the weight of WFPC2: At more than 272 kilograms (600 pounds), it was unwieldy even in the microgravity of low-

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Earth orbit. One of the instrument's mirrors, called the pickoff mirror, was mounted on a short arm located outside the protective casing. Merely bumping the mirror would misalign the system and essentially ruin the entire instrument. During WFPC2's construction, Trauger and colleagues showed a model of the instrument to an astronaut, who bumped the pickoff mirror. Trauger couldn't help but wonder, "Is this an omen?"

The leaders of the WFPC2 team traveled to NASA's Kennedy Space Center in Florida for the early morning launch on Dec. 2, 1993. After departing Kennedy and seeking out an early breakfast, Gallagher remembers looking up at the predawn sky to see the space shuttle passing overhead and nearing Hubble; the objects appeared as two faint points of light in the sky as they orbited Earth.

On the sixth day of the mission, astronauts Jeffrey Hoffman and Story Musgrave conducted a spacewalk to remove WFPC from Hubble and install WFPC2. Everything seemed to go as planned, but the real test was yet to come.

The astronauts returned to Earth on Dec. 13, and the first raw data from WFPC2 came back on Dec. 18. The team put the data through the image-processing software and watched anxiously as the pictures began to ratchet across the screen. There was instant relief.

“They were sharp,” Trauger said of the images. “And it wasn’t just that we had pictures that looked amazing, it was that we were making new discoveries right away. There were things in the images that we’d never seen before.”

NASA released those first images to the public on Jan. 13, 1994. The next day, the WFPC2 team presented the results to an overflow audience at the winter meeting of the American Astronomical Society.

“When we showed the first images, the room erupted; we got a standing ovation,” Trauger said. “You don’t usually see that at an astronomy meeting!”

The WFPC2 instrument operated on Hubble for over 15 years and took more than 135,000 observations of the universe. More than 3,500 science papers were written based on that data before the instrument was retired in 2009, and over 2,000 more have been published since.

“WFPC2 didn’t succeed by magic or luck; it succeeded because we had a competent and hardworking group of people who understood what was at stake and stepped up to the challenge,” Gallagher said. “And just like with every project, I wish I could have transported that team with me to the next mission.”

In May of 2009, astronauts removed WFPC2 from Hubble and replaced it with the Wide Field Camera 3 (WFC3), which continues to operate today — 28 years after Hubble first switched on. WFPC2 was later placed on public display at the Smithsonian Air and Space Museum in Washington, D.C.


For more information about NASA's Hubble Space Telescope, visit http://www.nasa.gov/hubble.

Self-driving Rovers Tested in Mars-Like Morocco

Robots invaded the Sahara Desert for Europe's largest rover field test, taking place in a Mars-like part of Morocco. For two weeks, three rovers and more than 40 engineers tested automated navigation systems at up to five different sites. This marked the end of the first phase of the strategic research cluster on space robotics technologies, a scheme funded by the European Union's Horizon 2020 program.

The cluster is coordinated by the PERASPERA Ad Astra (Latin for 'to the stars through hardships') project, which is a partnership of Italy's ASI space agency, France's CNES space agency, the DLR German Aerospace Center, Spain's CDTI technology agency, and the UK Space Agency, UKSA, coordinated by ESA.

The venue for the field test — organized by Germany's DFKI Robotics Innovation Centre — was a site served by the Ibn Battuta Centre, near Erfoud on the northern edge of the Sahara Desert. The wind-blown desert environment was selected by the EU's Europlanet Research Infrastructure as a good match for Mars, and many others agree: the teams ended up sharing the location with a Hollywood feature film crew and Chinese documentary makers.

“What this kind of field test gives you is the proof of the pudding that your design is working well, even in some of the most challenging environments we can imagine,” explains Gianfranco Visentin, head of ESA's Automation and Robotics section.

“Lab testing of the hardware we design doesn’t take account of the variability nature brings, from the light of the sky to the shape of the landscape, the texture and colors of the sand and rock. Operating outdoors in this way proves that our systems work in much more complex and elaborate settings than can ever be simulated.

“To give an example during this field test, the very smoothness and homogeneity of some of the big sand dunes proved difficult for computer vision algorithms to navigate, because they are based on identifying features based on difference, so they started to behave in unexpected ways we haven't
seen before.

“Our excellent results also included some good successes: the SherpaTT rover managed a 1.3-kilometer [0.8-mile] journey on an entirely autonomous basis, while its autonomous science element triggered a scientific acquisition on its own, unprompted: it spotted some strange shaped stones then asked the main planner to move into a better position to take more images.

“This is important for the future, when there will be many more rovers going to Mars and they'll be moving hundreds of meters per day. There won't be schools of analysts to scrutinize every image — intelligent rover systems will be needed to detect what is interesting and send it back to Earth.”

As an essential contribution before testing began, ESA flew a drone to map the location, producing digital elevation models down to a resolution of 4 centimeters (1.57 inches). This ‘ground truthing' was needed to compare rover data with observed reality. The combination of ESA's map and the data collected by the different rovers constitutes the largest analog test dataset ever made and it will be used to validate algorithms for ESA's own activities.

The field test included participants from Germany's DFKI and DLR Institute of Robotics and Mechatronics, Space Application Services in Belgium, Magellium and the Laboratory for Analysis and Architecture of Systems (LAAS) in France, GMV in Spain, and Kings College London and Airbus in the UK.

PERASPERA is set to move to a new phase, building on the results demonstrated in the field test, culminating in a space mission to demonstrate orbital robotics around 2023.

For more information, please visit http://www.esa.int/Our_Activities/Space_Engineering_Technology/Self-driving_rovers_tested_in_Mars-like_Morocco.

**Rosetta Witnesses Birth Of Baby Bow Shock Around Comet**

A new study reveals that, contrary to first impressions, Rosetta did detect signs of an infant bow shock at the comet it explored for two years — the first ever seen forming anywhere in the solar system.

From 2014 to 2016, ESA's Rosetta spacecraft studied Comet 67P/Churyumov-Gerasimenko and its surroundings from near and far. It flew directly through the ‘bow shock' several times both before and after the comet reached its closest point to the Sun along its orbit, providing a unique opportunity to gather in situ measurements of this intriguing patch of space.

Comets offer scientists an extraordinary way to study the plasma in the solar system. Plasma is a hot, gaseous state of matter comprising charged particles, and is found in the solar system in the form of the solar wind: a constant stream of particles flooding out from our star into space.

As the supersonic solar wind flows past objects in its path, such as planets or smaller bodies, it first hits a boundary known as a bow shock. As the name suggests, this phenomenon is somewhat like the wave that forms around the bow of a ship as it cuts through choppy water.

Bow shocks have been found around comets, too — Halley's comet being a good example. Plasma phenomena vary as the medium interacts with the surrounding environment, changing the size, shape, and nature of structures such as bow shocks over time.

Rosetta looked for signs of such a feature over its two-year mission, and ventured over 1,500 kilometers (932 miles) away from 67P's center on the hunt for large-scale boundaries around the comet — but apparently found nothing.

“We looked for a classical bow shock in the kind of area we'd expect to find one, far away from the comet's nucleus, but didn't find any, so we originally reached the conclusion that Rosetta had failed to spot any kind of shock,” says Herbert Gunell of the Royal Belgian Institute for Space Aeronomy, Belgium, and Umeå University, Sweden, one of the two scientists who led the study.

“However, it seems that the spacecraft actually did find a bow shock, but that it was in its infancy. In a new analysis of the data, we eventually spotted it around 50 times closer to the comet's nucleus than anticipated in the case of 67P. It also moved in ways we didn't expect, which is why we initially missed it.”

On March 7, 2015, when the comet was over twice as far from the Sun as the Earth and heading inwards towards our star, Rosetta data showed signs of a bow shock beginning to form. The same indicators were present on its way back out from the Sun, on February 24, 2016. This boundary was observed to be asymmetric, and wider than the fully developed bow shocks observed at other comets.

“Such an early phase of the development of a bow shock around a comet had never been captured before Rosetta,” says co-lead Charlotte Goetz of the Institute for Geophysics and Extraterrestrial Physics in Braunschweig, Germany.
“The infant shock we spotted in the 2015 data will have later evolved to become a fully developed bow shock as the comet approached the Sun and became more active — we didn’t see this in the Rosetta data, though, as the spacecraft was too close to 67P at that time to detect the ‘adult’ shock. When Rosetta spotted it again, in 2016, the comet was on its way back out from the Sun, so the shock we saw was in the same state but ‘uniforming’ rather than forming.”

Herbert, Charlotte, and colleagues explored data from the Rosetta Plasma Consortium, a suite of instruments comprising five different sensors to study the plasma surrounding Comet 67P. They combined the data with a plasma model to simulate the comet’s interactions with the solar wind and determine the properties of the bow shock.

The scientists found that, when the forming bow shock washed over Rosetta, the comet’s magnetic field became stronger and more turbulent, with bursts of highly energetic charged particles being produced and heated in the region of the shock itself. Beforehand, particles had been slower-moving, and the solar wind had been generally weaker — indicating that Rosetta had been ‘upstream’ of a bow shock.

“These observations are the first of a bow shock before it fully forms, and are unique in being gathered on-location at the comet and shock itself,” says Matt Taylor, ESA Rosetta Project Scientist.

“This finding also highlights the strength of combining multi-instrument measurements and simulations. It may not be possible to solve a puzzle using one dataset, but when you bring together multiple clues, as in this study, the picture can become clearer and offer real insight into the complex dynamics of our solar system — and the objects in it, like 67P.”

For more information, visit http://www.esa.int/Our_Activities/Space_Science/Rosetta/Rosetta_witnesses_birth_of_baby_bow_shock_around_comet.

**Mars Express gets Festive: A Winter Wonderland on Mars**

This shows what appears to be a large patch of fresh, untrodden snow — a dream for any lover of the holiday season. However, it’s a little too distant for a last-minute winter getaway: this feature, known as Korolev Crater, is found on Mars and is shown here in beautiful detail as seen by Mars Express.

ESA’s Mars Express mission launched on June 2, 2003, and reached Mars six months later. The satellite fired its main engine and entered orbit around the red planet on December 25, making this the 15-year anniversary of the spacecraft’s orbit insertion and the beginning of its science program.

These images are an excellent celebration of such a milestone. Taken by the Mars Express High Resolution Stereo Camera (HRSC), this view of Korolev Crater comprises five different ‘strips’ that have been combined to form a single image, with each strip gathered over a different orbit. The crater is also shown in perspective, context, and topographic views, all of which offer a more complete view of the terrain in and around the crater.

Korolev Crater is 82 kilometers (51 miles) across and found in the northern lowlands of Mars, just south of a large patch of dune-filled terrain that encircles part of the planet’s northern polar cap (known as Olympia Undae). It is an especially well-preserved example of a martian crater and is filled not by snow but ice, with its center hosting a mound of water ice some 1.8 kilometers/1 mile thick all year round.

This ever-icy presence is due to an interesting phenomenon known as a ‘cold trap’, which occurs as the name suggests. The crater’s floor is deep, lying some 2 kilometers (1.24 miles) vertically beneath its rim. The very deepest parts of Korolev Crater, those containing ice, act as a natural cold trap: the air moving over the deposit of ice cools down and sinks, creating a layer of cold air that sits directly above the ice itself. Behaving as a shield, this layer helps the ice remain stable and stops it from heating up and disappearing. Air is a poor conductor of heat, exacerbating this effect and keeping Korolev Crater permanently icy.

The crater is named after chief rocket engineer and spacecraft designer Sergei Korolev, dubbed the father of Soviet space technology. Korolev worked on a number of well-known missions including the Sputnik program (the first artificial satellites ever sent into orbit around the Earth in 1957 and the years following), the Vostok and Voskhod programs of human space exploration (Vostok being the spacecraft that carried the first ever human, Yuri Gagarin, into space in 1961), as well as the first interplanetary missions to the Moon, Mars, and Venus. He also worked on a number of rockets that were the precursors to the successful Soyuz launcher — still the workhorses of the Russian space program, and used for both crewed and robotic flights.

This region of Mars has also been of interest to other missions, including ESA’s ExoMars program, which aims to establish if life ever existed on Mars.
Holiday Asteroid Flyby

These three radar images of near-Earth asteroid 2003 SD220 were obtained on December 15-17, by coordinating observations with NASA's 70-meter (230-foot) antenna at the Goldstone Deep Space Communications Complex in California and the National Science Foundation's (NSF) 100-meter (330-foot) Green Bank Telescope in West Virginia. Credit: NASA/JPL-Caltech/GSSR/NSF/GBO.

The December 2018 close approach by the large, near-Earth asteroid 2003 SD220 has provided astronomers an outstanding opportunity to obtain detailed radar images of the surface and shape of the object and to improve the understanding of its orbit.

The asteroid flew safely past Earth on December 22, at a distance of about 2.9 million kilometers (1.8 million miles). This was the asteroid's closest approach in more than 400 years and the closest until 2070, when the asteroid will safely approach Earth slightly closer.

The radar images reveal an asteroid with a length of at least 1.6 kilometers (1 mile) and a shape similar to that of the exposed portion of a hippopotamus wading in a river. They were obtained December 15-17 by coordinating the observations with NASA's 70-meter (230-foot) antenna at the Goldstone Deep Space Communications Complex in California, the National Science Foundation's 100-meter (330-foot) Green Bank Telescope in West Virginia and the Arecibo Observatory's 305-meter (1,000-foot) antenna in Puerto Rico.

The Green Bank Telescope was the receiver for the powerful microwave signals transmitted by either Goldstone or the NASA-funded Arecibo planetary radar in what is known as a “bistatic radar configuration.” Using one telescope to transmit and another to receive can yield considerably more detail than would one telescope, and it is an invaluable technique to obtain radar images of closely approaching, slowly rotating asteroids like this one.

“The radar images achieve an unprecedented level of detail and are comparable to those obtained from a spacecraft flyby,” said Lance Benner of the Jet Propulsion Laboratory in Pasadena, California, and the scientist leading the observations from Goldstone. “The most conspicuous surface feature is a prominent ridge that appears to wrap partway around the asteroid near one end. The ridge extends about 330 feet [100 meters] above the surrounding terrain. Numerous small bright spots are visible in the data and may be reflections from boulders. The images also show a cluster of dark, circular features near the right edge that may be craters.”

The images confirm what was seen in earlier “light curve” measurements of sunlight reflected from the asteroid and from earlier radar images by Arecibo: 2003 SD220 has an extremely slow rotation period of roughly 12 days. It also has what seems to be a complex rotation somewhat analogous to a poorly thrown football. Known as “non-principal axis” rotation, it is uncommon among near-Earth asteroids, most of which spin about their shortest axis.

With resolutions as fine as 3.7 meters (12 feet) per pixel, the detail of these images is 20 times finer than that obtained during the asteroid's previous close approach to Earth three years ago, which was at a greater distance. The new radar data will provide important constraints on the density distribution of the asteroid’s interior — information that is available on very few near-Earth asteroids.

“This year, with our knowledge about 2003 SD220's slow rotation, we were able to plan out a great sequence of radar images using the largest single-
dish radio telescopes in the nation,” said Patrick Taylor, senior scientist with Universities Space Research Association (USRA) at the Lunar and Planetary Institute (LPI) in Houston.

“The new details we've uncovered, all the way down to 2003 SD220's geology, will let us reconstruct its shape and rotation state, as was done with Bennu, target of the OSIRIS-REx mission,” said Edgard Rivera-Valentin, USRA scientist at the LPI. “Detailed shape reconstruction lets us better understand how these small bodies formed and evolved over time.”

Patrick Taylor led the bistatic radar observations with Green Bank Observatory, home of the Green Bank Telescope, the world's largest fully steerable radio telescope. Rivera-Valentin will be leading the shape reconstruction of 2003 SD220 and led the Arecibo Observatory observations.

Asteroid 2003 SD220 was discovered on Sept. 29, 2003, by astronomers at the Lowell Observatory Near-Earth-Object Search (LONEOS) in Flagstaff, Arizona — an early Near-Earth Object (NEO) survey project supported by NASA that is no longer in operation. It is classified as being a “potentially hazardous asteroid” because of its size and close approaches to Earth's orbit. However, these radar measurements further refine the understanding of 2003 SD220's orbit, confirming that it does not pose a future impact threat to Earth.

For more information about planetary defense, please visit https://www.nasa.gov/planetarydefense.

**NASA's Voyager 2 Probe Enters Interstellar Space**

For the second time in history, a human-made object has reached the space between the stars. NASA's Voyager 2 probe now has exited the heliosphere — the protective bubble of particles and magnetic fields created by the Sun.

Comparing data from different instruments aboard the trailblazing spacecraft, mission scientists determined the probe crossed the outer edge of the heliosphere on November 5, 2018. This boundary, called the heliopause, is where the tenuous, hot solar wind meets the cold, dense interstellar medium. Its twin, Voyager 1, crossed this boundary in 2012, but Voyager 2 carries a working instrument that will provide first-of-its-kind observations of the nature of this gateway into interstellar space.

Voyager 2 now is slightly more than 18 billion kilometers (11 billion miles) from Earth. Mission operators still can communicate with Voyager 2 as it enters this new phase of its journey, but information — moving at the speed of light — takes about 16.5 hours to travel from the spacecraft to Earth. By comparison, light traveling from the Sun takes about eight minutes to reach Earth.

The most compelling evidence of Voyager 2's exit from the heliosphere came from its onboard Plasma Science Experiment (PLS), an instrument that stopped working on Voyager 1 in 1980, long before that probe crossed the heliopause. Until recently, the space surrounding Voyager 2 was filled predominantly with plasma flowing out from our Sun. This outflow, called the solar wind, creates a bubble — the heliosphere — that envelopes the planets in our solar system. The PLS uses the electrical current of the plasma to detect the speed, density, temperature, pressure and flux of the solar wind. The PLS aboard Voyager 2 observed a steep decline in the speed of the solar wind particles on Nov. 5. Since that date, the plasma instrument
has observed no solar wind flow in the environment around Voyager 2, which makes mission scientists confident the probe has left the heliosphere.

“Working on Voyager makes me feel like an explorer, because everything we’re seeing is new,” said John Richardson, principal investigator for the PLS instrument and a principal research scientist at the Massachusetts Institute of Technology in Cambridge. “Even though Voyager 1 crossed the heliopause in 2012, it did so at a different place and a different time, and without the PLS data. So we're still seeing things that no one has seen before.”

In addition to the plasma data, Voyager's science team members have seen evidence from three other onboard instruments — the cosmic ray subsystem, the low energy charged particle instrument and the magnetometer — that is consistent with the conclusion that Voyager 2 has crossed the heliopause. Voyager’s team members are eager to continue to study the data from these other onboard instruments to get a clearer picture of the environment through which Voyager 2 is traveling.

“There is still a lot to learn about the region of interstellar space immediately beyond the heliopause,” said Ed Stone, Voyager project scientist based at Caltech in Pasadena, California.

Together, the two Voyagers provide a detailed glimpse of how our heliosphere interacts with the constant interstellar wind flowing from beyond. Their observations complement data from NASA's Interstellar Boundary Explorer (IBEX), a mission that is remotely sensing that boundary. NASA also is preparing an additional mission — the upcoming Interstellar Mapping and Acceleration Probe (IMAP), due to launch in 2024 — to capitalize on the Voyagers' observations.

“Voyager has a very special place for us in our heliophysics fleet,” said Nicola Fox, director of the Heliophysics Division at NASA Headquarters. “Our studies start at the Sun and extend out to everything the solar wind touches. To have the Voyagers sending back information about the edge of the Sun’s influence gives us an unprecedented glimpse of truly uncharted territory.”

While the probes have left the heliosphere, Voyager 1 and Voyager 2 have not yet left the solar system, and won't be leaving anytime soon. The boundary of the solar system is considered to be beyond the outer edge of the Oort Cloud, a collection of small objects that are still under the influence of the Sun's gravity. The width of the Oort Cloud is not known precisely, but it is estimated to begin at about 1,000 astronomical units (AU) from the Sun and to extend to about 100,000 AU. One AU is the distance from the Sun to Earth. It will take about 300 years for Voyager 2 to reach the inner edge of the Oort Cloud and possibly 30,000 years to fly beyond it.

The Voyager probes are powered using heat from the decay of radioactive material, contained in a device called a radioisotope thermal generator (RTG). The power output of the RTGs diminishes by about four watts per year, which means that various parts of the Voyagers, including the cameras on both spacecraft, have been turned off over time to manage power.

“I think we’re all happy and relieved that the Voyager probes have both operated long enough to make it past this milestone,” said Suzanne Dodd, Voyager project manager at NASA’s Jet Propulsion Laboratory (JPL) in Pasadena, California. “This is what we’ve all been waiting for. Now we’re looking forward to what we’ll be able to learn from having both probes outside the heliopause.”

Voyager 2 launched in 1977, 16 days before Voyager 1, and both have traveled well beyond their original destinations. The spacecraft were built to last five years and conduct close-up studies of Jupiter and Saturn. However, as the mission continued, additional flybys of the two outermost giant planets, Uranus and Neptune, proved possible. As the spacecraft flew across the solar system, remote-control reprogramming was used to endow the Voyagers with greater capabilities than they possessed when they left Earth. Their two-planet mission became a four-planet mission. Their five-year lifespans have stretched to 41 years, making Voyager 2 NASA’s longest running mission.

The Voyager story has impacted not only generations of current and future scientists and engineers, but also Earth’s culture, including film, art and music. Each spacecraft carries a Golden Record of Earth sounds, pictures, and messages. Since the spacecraft could last billions of years, these circular time capsules could one day be the only traces of human civilization.

For more information about the Voyager mission, visit https://www.nasa.gov/voyager.
NASA’s Dawn Mission to Asteroid Belt Comes to End

NASA’s Dawn spacecraft has gone silent, ending a historic mission that studied time capsules from the solar system’s earliest chapter.

The spacecraft finally ran out of hydrazine, the fuel that enables the spacecraft to control its pointing. Dawn can no longer keep its antennae trained on Earth to communicate with mission control or turn its solar panels to the Sun to recharge.

The Dawn spacecraft launched 11 years ago to visit the two largest objects in the main asteroid belt. Currently, it’s in orbit around the dwarf planet Ceres, where it will remain for decades.

“Today, we celebrate the end of our Dawn mission — its incredible technical achievements, the vital science it gave us, and the entire team who enabled the spacecraft to make these discoveries,” said Thomas Zurbuchen, associate administrator of NASA’s Science Mission Directorate in Washington. “The astounding images and data that Dawn collected from Vesta and Ceres are critical to understanding the history and evolution of our solar system.”

Dawn launched in 2007 on a journey that put about 6.9 billion kilometers (4.3 billion miles) on its odometer. Propelled by ion engines, the spacecraft achieved many firsts along the way. In 2011, when Dawn arrived at Vesta, the second largest world in the main asteroid belt, the spacecraft became the first to orbit a body in the region between Mars and Jupiter. In 2015, when Dawn went into orbit around Ceres, a dwarf planet that is also the largest world in the asteroid belt, the mission became the first to visit a dwarf planet and go into orbit around two destinations beyond Earth.
"The fact that my car's license plate frame proclaims, 'My other vehicle is in the main asteroid belt,' shows how much pride I take in Dawn," said Mission Director and Chief Engineer Marc Rayman at NASA's Jet Propulsion Laboratory. "The demands we put on Dawn were tremendous, but it met the challenge every time. It's hard to say goodbye to this amazing spaceship, but it's time."

The data Dawn beamed back to Earth from its four science experiments enabled scientists to compare two planet-like worlds that evolved very differently. Among its accomplishments, Dawn showed how important location was to the way objects in the early solar system formed and evolved. Dawn also reinforced the idea that dwarf planets could have hosted oceans over a significant part of their history — and potentially still do.

"In many ways, Dawn's legacy is just beginning," said Principal Investigator Carol Raymond at JPL. "Dawn's data sets will be deeply mined by scientists working on how planets grow and differentiate, and when and where life could have formed in our solar system. Ceres and Vesta are important to the study of distant planetary systems, too, as they provide a glimpse of the conditions that may exist around young stars."

Because Ceres has conditions of interest to scientists who study chemistry that leads to the development of life, NASA follows strict planetary protection protocols for the disposal of the Dawn spacecraft. Dawn will remain in orbit for at least 20 years, and engineers have more than 99% confidence the orbit will last for at least 50 years.

So, while the mission plan doesn't provide the closure of a final, fiery plunge — the way NASA's Cassini spacecraft ended last year, for example — at least this is certain: Dawn spent every last drop of hydrazine making science observations of Ceres and radioing them back so we could learn more about the solar system we call home.

The topical conference Differentiation: Building the Internal Architecture of Planets was held May 7-10, 2018, in Pasadena, California. This was the second conference in the LPI’s The First Billion Years initiative. It focused on how planetary differentiation created the basic architecture of the planets and established the initial chemical and physical conditions for all subsequent stages of planetary evolution.

The conference began with an optional one-day field trip to the San Gabriel Mountains north of Pasadena. The principal focus of the trip was the 1.2-Ga San Gabriel Anorthosite as an analog for the lunar magma ocean. Additional field stops included the metamorphic basement rocks, Mesozoic-aged plutonic rocks, hydrous alteration of subduction zone rocks, and the fault geology of southern California.

The final three days of the meeting focused on oral presentations, with abundant time reserved for discussion and questions from the audience. Presentations were organized by increasing planetary size, including partially- and fully-differentiated meteorite parent bodies, ice-rich objects, the Moon, Mars, and Earth. A broad range of topics were included in these presentations, including the overlap between planetary accretion and
The First Billion Years — Bombardment: Shaping Planetary Surfaces and Their Environments

The LPI's First Billion Years initiative is designed to support an interdisciplinary study of planetary accretion, differentiation, bombardment, and habitability in a series of four topical conferences. The third installment in that series, Bombardment, investigated the range of collisional events that occurred after planetary accretion when an extended period of bombardment may have been punctuated by one or more bursts of activity. The largest impactors produced impact basins hundreds to thousands of kilometers in diameter, completely reshaping the surfaces of rocky and icy planets. These types of events were not unique to our solar system. Debris disks produced by similar processes have been observed around other stars after they emerged from their natal gas-rich nebulae and up to several hundred million years after they formed. Although the Moon was a central component of the conference due to its exquisitely preserved record, the discussion necessarily included observations elsewhere, such as on the Hadean Earth, Mars, the asteroid belt, outer solar system moons, and planetary systems elsewhere. Because the bombardment may have affected the origin and early evolution of life, discussion also drew on astrobiological findings.

Before those discussions kicked off, conference participants made a trip to Meteor Crater, Arizona. The group had an opportunity to see first hand how astronomical and geological forces can shape a planetary surface. The excursion provided ample opportunity to discuss the nature of impacting objects, crater excavation processes, the development of ejecta blankets, and some of the environmental effects of impact events, both large and small. Importantly, the group also had an opportunity to see the types of geologic samples available around an impact crater and discuss how we can use the characteristics of related lunar samples to better infer their provenance. The group made good use of the second edition of the LPI's award-winning Guidebook to the Geology of Barringer Meteorite Crater, Arizona (a.k.a. Meteor Crater).

Back in Flagstaff, the meeting was launched by a fascinating presentation by Kate Su (University of Arizona), who spoke about astronomical observations of debris disks that provide insights to the types of bombardment that occur around young stars. That was the first of a series of oral sessions that explored the first billion years of a planetary system's history. "Astronomical Observations" of collisions in exoplanetary systems provided a potential snapshot of the types of events that affected our own solar system. "Geochemical, Geological, and Petrological Observations" used analyses of the rock record to extract clues about the last phase of accretion and the latest portion of a subsequent period of bombardment. "Ages of Impacts Part I and Part II" presented geochronologic and geological data used to determine the absolute and relative timing of impacts during the (lunar) basin-forming epoch.

Those data-rich sessions were followed by "Developing Models Consistent with the Data," which not only drew on existing data, but also provided hints of future work. That set the stage for the session "Future Tests," which recognized that the new NASA Lunar Exploration Campaign will provide opportunities to test several of the hypotheses being discussed. That discussion was guided by chairs Heather Meyer (LPI) and Gregory Neumann (NASA Goddard Space Flight Center).

Those sessions revealed three fault lines in the community: (1) argon-argon lunar impact ages and their implications for early solar system bombardment are often misunderstood; (2) It is unclear if the size frequency distribution (SFD) of surface craters can be integrated with subsurface...
gravity signatures of additional craters to obtain a revised SFD of impactors; and (3) the geological and lithological products of impact-cratering processes on the Moon are apparently mysterious, not only in an exciting way ripe with discovery, but also in a disappointing way reflective of confusion. That latter point is a reminder that the planetary science field has drifted far from the talents of those involved in Apollo. If we are going to press forward with new lunar and planetary surface operations, training programs like those at Meteor Crater will be essential for safe and productive missions.

Conference attendees then turned their attention to related topics: “The Early Earth Record,” “The Last Billion Years,” and “Bombardment and Implications for Habitability,” guided by chairs Simone Marchi (Southwest Research Institute), David Minton (Purdue University), and Nicole Zellner (Albion College). A wonderfully engaging closing presentation was provided by Penelope Boston (Director, NASA Astrobiology Institute), who drew out the biological threads in the meeting and provided an inspired transition to the Habitability conference, which is the next (and final) installment in LPI’s First Billion Years initiative. For those interested in the conference finale, make plans for visiting Wyoming and Montana September 8–12, 2019. The meeting will begin with a one-day excursion to Yellowstone National Park to explore the biologic potential of hydrothermal systems in volcanic settings and to spark discussion of a similar potential in impact-generated hydrothermal systems that may have existed during the dawn of life nearly 4 billion years ago. The field trip will be followed by presentations and discussion of planetary habitability, the production of conditions conducive to life, the emergence of life on Earth, the potential for abiogenesis on other solar system bodies, and extensions to extrasolar systems.

For more information, including links to the program and abstracts, visit the meeting website at https://www.hou.usra.edu/meetings/bombardment2018/.

— David A. Kring, Convener, Lunar and Planetary Institute

Mars Workshop on Amazonian and Present-Day Climate

In mid-June, more than 30 Mars scientists and 17 students gathered in Lakewood, Colorado to outline the current understanding of active processes and environmental conditions occurring within the recent “Amazonian” and present-day martian climate, and the atmospheric and geologic records that those processes and conditions have created. This meeting was intended as a supplemental topical workshop, held between the most recent International Conference on Mars Polar Science and Exploration in 2016 and the one planned for 2020.

The meeting was convened by the Planetary Science Institute (Colorado location), with student travel grants funded by NASA’s Mars Program Office and program organization assistance from the Lunar and Planetary Institute. The conference received 41 abstracts, which were organized based on their focus: the atmosphere, polar caps and layered deposits (PLDs), surface changes, and non-polar features. Bruce Jakosky (Colorado University, Boulder) gave a keynote presentation focused on the history of water on Mars. All oral sessions featured substantial discussion time to allow for synthesis of individual topics and results into the scientific advancement of the bigger-picture understanding of Mars’ climate. Additionally, a poster session, pre-workshop social event, and mid-workshop field trip provided opportunities for attendees to share data, results, and ideas.

From the discussions, a consensus emerged that a top science objective for Mars Amazonian Climate studies is to identify, measure, and interpret the surface and subsurface record of Mars’ climate history. In particular, it is important to establish if and how the PLDs and other landforms and surface/subsurface materials record climate variations over annual-to-decadal, orbital (e.g., obliquity cycles), and/or longer timescales — so that we can begin to quantitatively read that record from high-resolution orbital images. Part of this work depends on gaining a strong understanding of
current atmospheric processes and exchanges of volatiles with the surface/near-surface. Specifically, characterizing volatile reservoirs that presently or formerly exchange with the atmosphere and understanding how dust/clouds affect surface and atmospheric temperatures would place key constraints on environmental conditions and habitable regions during the recent past.

A preliminary list of key open science questions was defined that reflected this objective, as well as how deeply polar conditions and processes interact with the global Mars geologic and atmospheric systems:

- What are the timescale, completeness, and temporal resolution recorded in PLDs?
- How can we identify and interpret geologic and atmospheric records that volatiles leave outside the polar regions?
- What are the present and past fluxes of volatiles, particulates, and energy across the globe?
- How much material is contained within dust/sand/ice reservoirs, how are they formed, preserved, or depleted, and when?
- What is the mass/energy balance at the poles?

At the conclusion of the workshop, discussion turned to mission implementation. Engineers from Ball Aerospace and the Jet Propulsion Laboratory contributed insights regarding potentially relevant technical capabilities. Landing on the surface to enable access to the ice and provide \textit{in situ} atmospheric and subsurface measurements was recommended by many participants. However, such a mission would potentially need to be capable of surviving the polar night, in addition to landing on and drilling into the martian polar cap. Measurements achievable by an orbiter were also discussed.

Contributions to a Planetary and Space Sciences special issue are welcome from the general community through February 28, 2019. We thank all attendees for contributing to the discussion, especially those who engaged in note-taking and additional synthesis discussion.

More information about the workshop, including the full program and abstracts, is available at https://www.hou.usra.edu/meetings/amazonian2018/.

**Experimental Analysis of the Outer Solar System Workshop**

With the growing need for more missions to the outer solar system and lack of data for certain planetary bodies, experimental laboratory work helps supplement mission planetary data and modeling. Laboratory work on the chemical and physical behaviors of ices can lead to surprising research, helping us better understand the processes that we detect and how to better our instrumentation for future probes or strengthen our modeling capabilities. This two-day workshop was convened to address the challenges and opportunities in current experimental techniques and findings of icy planetary bodies.

To explore how much we currently know about the technologies and instrumentation involved in the laboratory setting for learning about the outer solar system, and discuss the primary objectives for such instrumentations, the first Experimental Analysis of the Outer Solar System was held August 15‒16, 2018, in Fayetteville, Arkansas. This workshop sought to exchange ideas among experimentalists with common interests in surface or
irradiation processes, chemistry, geophysical, or kinetic processes on icy bodies. Topics included, but were not limited to, jovian moons, saturnian moons, atmospheres, characterization and roles of irradiation, chemical interactions, ice structures and spectroscopy, and developed techniques.

The workshop discussions led to the definition of several primary open scientific questions in this area currently:

- What are the thermodynamics and kinetics of dissolution mixtures on Titan's surface?
- What constraints in thermal properties for ocean world interiors can be found using mineral physics laboratories?
- How can we improve current phase diagrams of ice mixtures relevant to Kuiper belt objects?
- How can we test new instrument techniques regarding the hardness of hydrocarbons and cryogenic materials?

The workshop was convened by Caitlin Ahrens, Vincent Chevrier, and Larry Roe of the Arkansas Center for Space and Planetary Sciences. The program and abstracts are available on the workshop website at https://www.hou.usra.edu/meetings/exoss2018/.
Spotlight on Education

Public Engagement Opportunities at the 50th LPSC

A variety of public engagement opportunities for scientists, students, and the public will take place during the 2019 Lunar and Planetary Science Conference (LPSC).

Participate as a Reviewer, Mentor, or Presenter

The LPI invites planetary scientists to volunteer as reviewers for the Early Career Presenters Review and/or as a mentor for first-time attendees for LPSC Insights: Get Connected, Stay Connected. Volunteers are also requested for Sunday afternoon's public event Lunar Palooza; help engage the public in lunar science and exploration through presentations and/or hands-on activities! Please email education@lpi.usra.edu to volunteer as a reviewer, mentor, or presenter.

Scientist and Public Engagement Sessions

The LPI will be conducting sessions at LPSC for planetary scientists, students, and the general public.

Early Career Presenters Review

Students, post-docs, and other early career scientists preparing to present research at the 2019 LPSC are invited to present their oral or poster presentation and receive feedback from experienced scientists before presenting during the regular meeting. Details and registration are available on the LPSC website. Space is limited. Presenters, and scientists wishing to participate as reviewers, are encouraged to contact Andy Shaner at shaner@lpi.usra.edu with any questions.

LPSC Insights: Get Connected, Stay Connected

Are you attending LPSC for the first time? Are you unsure how to navigate the conference? Are you nervous about networking? First-time student attendees who register for this program will be introduced to an experienced LPSC attendee, and the pair will spend Monday afternoon, March 18, attending sessions and networking together. Details and registration are available on the LPSC website. First-time attendees and scientists wishing to participate as mentors are encouraged to contact Andy Shaner at shaner@lpi.usra.edu with any questions.

Planetary Scientist Workshop: Using Social Media to Share Your Science

Date and Time TBD
Planetary scientists attending LPSC are invited to this free workshop, where they will learn from experts about techniques and suggestions for disseminating their science through social media. For more information, please contact Christine Shupla at shupla@lpi.usra.edu.

Lunar Palooza

Scientists and public engagement specialists are welcome to participate in this year's public event. All members of the public, including students, educators, program leaders, amateur astronomers, and their families, are invited to the Lunar Palooza! Explore hands-on activities and hear the Apollo missions, ongoing lunar exploration, and future plans from experts attending LPSC! More details are available on the LPSC website. For more information, contact education@lpi.usra.edu.

Upcoming Public Event Opportunities

Upcoming opportunities exist for educator and public engagement around the broader topics of NASA planetary exploration. Contact local astronomical societies, planetariums and museums, local scientists, and NASA's Solar System Ambassadors (solarsystem.nasa.gov/ssa/directory.cfm) and ask them to join your events and share their experiences or resources with your audience.
Apollo 50th Anniversary

Celebrate the Apollo missions and their contributions to the field of planetary science. Learn more about NASA events and resources at https://www.nasa.gov/specials/apollo50th/.

Lyrids Meteor Shower, April 22-23, 2019

https://in-the-sky.org/news.php?id=20190423_10_100

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

SMD Research Opportunities for Graduate Students

NASA’s Science Mission Directorate (SMD) is inviting proposals for graduate student research via a new solicitation titled Future Investigators in NASA Earth and Space Science and Technology™ (FINESST) NNH19ZDA005K. The FINESST solicitation replaces the 2019 call for new NASA Earth and Space Science Fellowships. More information is available in NSPIRES (https://bit.ly/2zqG024). FINESST proposals are due at 11:59 pm eastern on February 1, 2019. Send questions by email to: HQ-FINESST@mail.nasa.gov.
Friedrich Begemann, 1927–2018

Friedrich (“Fred”) Begemann was born in late 1927 in the small village of Almena in Westphalia, close to the border of Lower Saxony and near the river Weser. Too young to get drafted for serious military service in World War II, he took up the study of physics at the University of Göttingen in 1947 and completed his diploma thesis, working with Friedrich Houtermans, who by then had returned to Göttingen after being forced to leave in 1933. When Houtermans moved to Bern, Switzerland, in 1952, Begemann followed him there (together with Johannes Geiss) to work on his Ph.D. thesis. In his work with Houtermans, Begemann dealt with the products of the radioactive decay of uranium and thorium into (eventually) isotopes of lead. He determined the half-life of radioactive Ra-E ($^{210}$Bi), an isotope in the decay chain leading from $^{238}$U to $^{206}$Pb, and applied the Ra-D ($^{210}$Pb) method suggested by Houtermans to determine a chemical age for minerals.

Following his Ph.D. work, Begemann moved to Chicago to work with Willard F. Libby as a Research Associate at the Enrico Fermi Institute. Here, he focused on tritium ($^3$H), the radioactive isotope of hydrogen, and over the following decade published a number of important papers on its abundance, origin, and distribution. This was a hot topic at the time due to the enormous amounts of tritium released into the environment from hydrogen bomb tests. Drawn to the group of Harald Urey and other researchers at Chicago, Begemann developed an interest in meteorites and analyses of stable noble gas isotopes, specifically $^3$He, the decay product of tritium. His paper with Johannes Geiss and D. C. Hess, in which they reported the first determination of a cosmic-ray exposure (CRE) age of a meteorite from combined tritium/$^3$He analysis, was a milestone article. Their work set the stage for the development of a completely new branch in meteoritics. Today, the study of cosmic-ray products in meteorites is a mature field. Not only does it provide the means to determine exposure ages, and therefore travel times from parent body to Earth, but it also puts constraints on their pre-atmospheric size — both very basic properties.

In 1957, Begemann joined Friedrich Paneth at the MPI-C in Mainz, where he remained until his retirement in 1995, interrupted only by a short stint as a Guest Professor at the University of Bern. While in Mainz he also became an adjunct professor at Johannes-Gutenberg University, teaching experimental physics in addition to doing research at the Max-Planck-Institute. While his early work in Mainz is still dominated by the study of radiation effects, including those found in the lunar samples returned by the Apollo missions, in time he began to focus more on the mass spectrometric determination of stable isotope compositions, noble gases in particular, but also elements like potassium and magnesium, where he was one of the first to confirm the existence in the early solar system of now-extinct $^{26}$Al from overabundances of $^{26}$Mg in calcium-aluminum-rich inclusions (CAIs).

Having already been appointed a “Scientific Member” of the Max-Planck Society in 1969, Begemann became the director of a new Department at the MPI-C in 1978, which he led until his retirement in 1995. This allowed him to expand this direction of research. A number of important contributions from this time dealt with noble gases in martian meteorites and the isotopes of noble gas and other trace elements in presolar grains. He also contributed to refined understanding of cosmic-ray interactions with meteorites by pointing out the “matrix effect” and by enabling the performance of irradiation simulation experiments on artificial meteorites. For this and his earlier work he was awarded the Leonard Medal of the Meteoritical Society in 1995. He also served the Society as a councilor from 1981 to 1984 and together with Heinrich Wänke organized the 1983 Annual Meeting with an unforgettable evening tour and dinner on the Rhine River.

Defining characteristics of Begemann were his analytical mind and sharp wit, which were second to none. He was able to detect the slightest flaw or uncertainty in someone’s logic, and would not hesitate to tell them so. Sometimes, this may have been hard to take, but we need such minds to challenge us.

— Text courtesy of Ulrich Ott and The Meteoritical Society
Christine Floss, 1961–2018

Dr. Christine Floss died unexpectedly at her home in St. Louis, Missouri, on April 19, 2018, at age 56. Floss was a research professor in the Department of Physics and McDonnell Center for Space Sciences at Washington University in St. Louis. She was a long-time member and a fellow of the Meteoritical Society, as well as an expert in the trace-element and isotopic analysis of planetary materials, meteorites, and presolar grains, studying the origin and evolution of the solar system. Floss was a gifted and dedicated scientist and mentor, and an extraordinary colleague, collaborator, and friend to many in the cosmochemistry and planetary science community.

Floss' research interests spanned a wide variety of extraterrestrial materials, from lunar samples to meteorites to presolar grains to returned samples from the NASA Stardust and Genesis missions to Antarctic micrometeorites to interplanetary dust particles. She played an important role in the chemical and isotopic studies of interplanetary dust particles, micrometeorites, and primitive chondrites to understand the origins and abundances of presolar and protosolar components in these materials. She performed isotopic and compositional studies of residues from Stardust craters and hypervelocity impact experiments to characterize the samples returned from Comet 81P/Wild 2. Identification and characterization of craters from the Stardust interstellar dust collector was also part of her scientific work. She played a leading role in trace-element-distribution studies of individual minerals in extraterrestrial samples, to understand their petrogenesis as well as secondary effects occurring on their parent bodies (thermal metamorphism, aqueous alteration).

Floss earned a B.A. in German from Purdue University in 1983; a second degree in Geology from Indiana University, Bloomington, in 1987; and a Ph.D. in Geochemistry from the Department of Earth and Planetary Sciences at Washington University in St. Louis in 1991. Her dissertation focused on rare-Earth-element (REE) distributions in meteorites (e.g., aubrites) and ferroan anorthosites, working with Ghislaine Crozaz. She showed that the heterogeneous REE patterns in oldhamite from aubrites reflect condensation from the solar nebula, rather than igneous processes in a parent body, as was believed at that time. It was during her time at Washington University that she developed her expertise with — and love of — the ion microprobe as her instrument of choice to explore the characteristics and origins of extraterrestrial materials.

Floss moved to Heidelberg, Germany, in 1991 for a research scientist position at the Max-Planck-Institut für Kernphysik. In 1993, while in Heidelberg, she married Frank Stadermann. While at the Max-Planck-Institut, she published on aubrites, angrites, pallasites, showing early on the breadth of her interests. She was also involved with trace-element studies of lunar samples (returning often to ferroan anorthosites), eucrites, lodranites, and acapulcoites.

In 1996, Floss and Stadermann were invited to return to Washington University to work with their former advisors, Robert Walker and Ghislaine Crozaz. Floss joined the Laboratory for Space Sciences, now a part of the McDonnell Center for the Space Sciences, as a research scientist, and through the ensuing years, worked her way up to becoming a full research professor. Floss worked with numerous colleagues, doing careful ion microprobe work that was essential in many studies. Along with Frank Stadermann, Ernst Zinner, and other coworkers, she developed unique expertise with the first Cameca NanoSIMS 50 instrument. Floss had over 250 coauthors and over 100 publications in peer-reviewed journals, and she led numerous research projects as principal investigator. In 2006, main-belt asteroid 6689 was named asteroid Floss.

In addition to her prolific research career, Floss played an active role in the cosmochemistry community. She was a member of the Antarctic Search for Meteorites (ANSMET) team in 2014–2015, a reflection of her adventurous spirit. She served the scientific community in many ways, as a member of the Antarctic Meteorite Working Group, the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM), the LPSC program committee, various student and early career award committees, the Council of the Meteoritical Society, and many NASA review panels. She also served as the associate editor for Meteoritics and Planetary Science from 2005 to 2015. All these activities reflected Floss’ personality and character; she was selfless, serious, level-headed, balanced and fair, always positive and never complaining, a consummate professional.

At Washington University, Floss had a special role. Following in the giant footsteps of the likes of Robert Walker, Ernst Zinner, and Thomas Bernatowicz, Christine took on the role of lead scientist for the NanoSIMS and Auger Electron Microprobe laboratories, and served as mentor extraordinaire to a new generation of cosmochemistry students and analysts. She was a wonderful advisor to both undergraduate and Ph.D. students; she always took the time to support all her students whenever they needed help, whether it was work-related or personal. In 2015, she was honored with a Washington University Outstanding Faculty Mentor award. All her graduate students received NASA Earth and Space Science Fellowships for their research, which further attests to her excellent mentoring. She carried on a great tradition of the McDonnell Center for the Space Sciences at Washington University in training and mentoring students who have become strong contributors in the field of space science and who will certainly carry on in the same spirit of scientific curiosity and excellence as she did.

— Text courtesy of The Meteoritical Society
Ian Stewart McCallum, geologist and professor emeritus at the University of Washington, Seattle, died peacefully of liver cancer on May 4, 2018, surrounded by his family in his home in Seattle. He was 80 years old.

McCallum was born on December 13, 1937, in a small, rural village near Stirling, Scotland. He attended Stirling High School and then St. Andrews University, where he played soccer and discovered his passion for geology. After graduating in 1960 with B.Sc. with first class honors, he emigrated to Canada, taking a job as an exploration geologist in western Quebec. In 1962, he moved to Chicago, where he resumed his studies at the University of Chicago. Six years later, with a Ph.D. in geology, McCallum moved to the University of Oregon for post-doctoral studies. In 1970 he was appointed to the faculty of what was then the Department of Geological Sciences at the University of Washington, where he spent the rest of his career. He retired in 2010.

McCallum was well known for seminal research in a number of areas. He elucidated the magmatic processes that have determined the character of the Moon, drawing analogy between lunar rocks and those in the Stillwater Complex, a layered mafic intrusion exposed in the Beartooth Mountains of Montana. He will long be remembered for his many outstanding contributions to our understanding of lunar crustal rock suites and the magmatic evolution of the Moon.

The Stillwater Complex was McCallum’s first love, however, and he studied it intensely for more than 20 years. There he and his students conducted the first modern stratigraphic study of the body and developed petrologic models to account for the unusual layering and the origin of its economically important platinum-group element deposit, for which the Stillwater is best known. Later in his career he turned his attention to the character and origin of Mount Baker, a subduction-related Cascade volcano.

McCallum never forgot his Scottish roots. His taciturn and unassuming character belied a gregarious streak that endeared him to colleagues and students alike. He was a masterful teacher, a brilliant mind and highly respected in his field, a gentle and thoughtful man, a lover of life, a devoted husband and father, and one who always put the needs of others above himself.

— Text courtesy of the University of Washington

Nancy Roman, 1925-2018

Astronomer Nancy Roman, the first woman to hold a senior leadership position at NASA, died on December 25 at the age of 93. After receiving her doctorate in astronomy from the University of Chicago in 1949, she remained at the university as a research associate until 1955, when she joined the Radio Astronomy Branch of the Naval Research Laboratory. In 1959, she moved to NASA, which had been established the year before. In 1960, she became chief of the agency's Astronomy and Relativity Programs, remaining in that job until her retirement from the agency in 1979. Among her achievements, Roman is best known for championing the project that became the Hubble Space Telescope, which launched in 1990 and is still in operation. An extensive oral history with Roman is available via the AIP Niels Bohr Library and Archives (https://bit.ly/2shKELH).
Bettina Inclán Named to Head NASA Office of Communications

Bettina Inclán has been named by Administrator Jim Bridenstine to be NASA’s Associate Administrator for Communications.

Inclán comes to NASA with over 15 years of experience as a communications specialist and strategist — building winning coalitions and crafting messages and crisis communications in the political, commercial, and nonprofit spheres. She has worked with major technology firms and non-profit organizations and has held senior roles with government leaders at the federal, state and local levels, including governors and within the U.S. House of Representatives.

At NASA, Inclán will direct internal and external communications for the agency and serve as a senior advisor to the Administrator and other executive leaders. She is responsible for managing an agency-wide staff of more than 100 that implements all aspects of NASA’s external and internal communications.

NASA Launches a New Podcast to Mars

NASA has a new mission to Mars, and it’s taking podcast listeners along for the ride.

The eight-episode series “On a Mission” follows the InSight lander as it traveled hundreds of millions of miles and lands on Mars on November 26. “On a Mission” will be the first JPL podcast to track a mission during flight, through interviews with the InSight team at NASA's Jet Propulsion Laboratory in Pasadena, California.

The episodes are available now at NASA, the InSight website, SoundCloud and Apple Podcasts. Episode One lays out the odds of reaching the surface safely — fewer than half of Mars missions make it.

“When things go beautifully it looks easy, but it’s really not easy,” said Sue Smrekar, deputy principal investigator for the InSight mission. “Any kind of exploration is just not easy or guaranteed — ever.”

Narrated by host and science journalist, Leslie Mullen, and InSight team members, each episode blends humor and captivating storytelling to dig into the journey of the lander and the people who have spent years working on it. New episodes, running between 20 and 30 minutes, were released weekly as InSight approached Mars. The final episode covers the InSight landing on the Red Planet.

The lander is the first robotic explorer to study the planet's “inner space” — its crust, mantle and core — in an effort to better understand the early formation of rocky planets in our inner solar system (Mercury, Venus, Earth and Mars) and rocky exoplanets.

Future seasons of the podcast will focus on different missions and take listeners on new journeys through the universe.

For the latest InSight updates, follow the mission on Facebook and Twitter.

To download and listen to “On a Mission” and other NASA podcasts, visit:

https://www.nasa.gov/podcasts

To learn more about InSight, visit:

https://mars.nasa.gov/insight/

NASA Announces New Partnerships for Commercial Lunar Payload Delivery Services

Nine U.S. companies now are eligible to bid on NASA delivery services to the lunar surface through Commercial Lunar Payload Services (CLPS) contracts, as one of the first steps toward long-term scientific study and human exploration of the Moon and eventually Mars.

These companies will be able to bid on delivering science and technology payloads for NASA, including payload integration and operations, launching from Earth and landing on the surface of the Moon. NASA expects to be one of many customers that will use these commercial landing services.

The selected companies are:

- Astrobotic Technology, Inc., Pittsburgh
- Deep Space Systems, Littleton, Colorado
- Draper, Cambridge, Massachusetts
Firefly Aerospace, Inc., Cedar Park, Texas  
Intuitive Machines, LLC, Houston  
Lockheed Martin Space, Littleton, Colorado  
Masten Space Systems, Inc., Mojave, California  
Moon Express, Cape Canaveral, Florida  
Orbit Beyond, Edison, New Jersey

NASA's Science Mission Directorate (SMD) initiated the request for proposals leading to these selections as the first step in achieving a variety of science and technology objectives that could be addressed by regularly sending instruments, experiments and other small payloads to the Moon. SMD serves as the NASA interface between the agency's mission directorates, the scientific community, and other external stakeholders in developing a strategy to enable an integrated approach for robotic and human exploration within NASA's Moon to Mars Exploration Campaign.

The Commercial Lunar Payload Services contracts are indefinite delivery, indefinite quantity contracts with a combined maximum contract value of $2.6 billion during the next 10 years. The agency will look at a number of factors when comparing the bids, such as technical feasibility, price and schedule.

Lunar payloads could fly on these contracted missions as early as 2019. In October, NASA issued a call for potential lunar instruments and technologies to study the Moon, with proposals due in January. These early missions will enable important technology demonstrations that will inform the development of future landers and other exploration systems needed for humans to return to the lunar surface, and help prepare the agency to send astronauts to explore Mars.

NASA will re-examine the private market periodically for new and emerging lunar delivery capabilities, and may offer additional companies an opportunity to join Commercial Lunar Payload Services through a contract process called on-ramping.

For more information about NASA's Moon to Mars exploration plans, visit:

https://www.nasa.gov/moontomars

**NASA Begins America’s New Moon to Mars Exploration Approach in 2018**

America's return to the Moon will begin with U.S. commercial delivery services of small scientific instruments, followed by development of an infrastructure in orbit around the Moon to support human missions to the lunar surface, Mars and destinations beyond, for decades to come.

Highlights from 2018 include:
• In October, NASA issued a call for lunar surface instruments and technology payloads that will fly to the Moon on commercial lunar landers as early as next year. On Nov. 29, the agency announced nine U.S. companies are eligible to bid on NASA delivery services to the lunar surface through Commercial Lunar Payload Services (CLPS) contracts.

• After receiving more than 190 scientific abstracts from the research community, NASA hosted a conference in February for scientists across a variety of disciplines to discuss future exploration and research using the Gateway, a spacecraft that will orbit the Moon and support human and robotic missions.

• In an effort to lay the foundation for partnerships with U.S. industry in several aspects of Gateway development and operation, NASA issued in 2018 several requests for information and ideas from U.S. companies about the Gateway's use and supply, as well as lunar payload transportation capabilities, and construction of its power and propulsion element.

• NASA continued to refine requirements for a U.S. habitat module for the Gateway and technology to use and process space-based resources through the Next Space Technologies for Exploration Partnerships-2 (NextSTEP-2).

The transportation system that will carry astronauts from Earth to the Gateway and help build the structure in orbit continued to take shape in 2018 with more flight hardware coming together around the country for the first launch of NASA's Space Launch System (SLS) rocket and Orion spacecraft.

• NASA delivered the second piece of SLS flight hardware to its Kennedy Space Center in Florida earlier this year. The Orion stage adapter will connect the spacecraft to SLS and will be loaded with 13 small satellites on the first mission.

• Engineers are completing final outfitting and assembly of the five major structural pieces of the SLS core stage at NASA's Michoud Assembly Facility in New Orleans.

• Engineers at NASA's Marshall Space Flight Center in Huntsville, Alabama, are putting the finishing touches on the 30-foot-tall launch vehicle stage adapter, which will connect SLS' core stage to the interim cryogenic propulsion stage delivered to Kennedy last year.

• Engineers at Kennedy installed Orion's reentry heat shield

• ESA (European Space Agency) delivered to Kennedy the service module that will propel, power and cool Orion during the first integrated flight test with SLS – Exploration Mission 1

• Workers at Kennedy also completed construction on the main flame deflector at Launch Pad 39B, and engineers installed the final umbilical on the mobile launcher before rolling the massive tower on Crawler-Transporter 2 to the pad.

It was a great year for robotic exploration of Mars, as well:

• NASA's Curiosity rover identified fragments of complex organic molecules in the shallow surface of Mars, giving us further evidence that the Red Planet could have hosted life at one point.

• NASA launched and landed the first spacecraft to set down on the Red Planet since Curiosity arrived in 2012 – the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight). InSight touched down on Martian soil in November to study the planet's interior and, just 10 days after landing, provided the first ever “sounds” of winds on Mars.

• NASA also announced the landing site for its next Red Planet rover, Mars 2020, which will continue the agency's efforts to search for evidence of life and prepare for human arrival.

Other highlights in the agency's progress this year in supporting the new Moon to Mars exploration approach include:

• More than 4,300 hours of testing completed on Solar Electric Propulsion (SEP) Hall thrusters.

• Orion pressure vessel for first crewed flight shipped to Kennedy.

• Final test of Orion's parachute system.

• Preparation for test of Orion's launch abort system.

• Several parts of SLS in production, or completed, for second mission.

• New series of SLS RS-25 engine test firings included nine tests of 3D-printed parts.
• First combination 3D printer and recycler launched to International Space Station to demonstrate new in-space manufacturing technology.
• NASA solicited new ways to manage trash on deep space missions.
• Ten companies chosen to conduct studies and advance technologies to collect and use space-based resources.
• 3D-Printed Habitat Challenge progressed as participating teams created digital models of Martian habitats and constructed and tested foundation prototypes.

New and Noteworthy

**Dynamic Mars: Recent and Current Landscape Evolution of the Red Planet**

*Dynamic Mars: Recent and Current Landscape Evolution of the Red Planet* presents the latest observations, interpretations, and explanations of geological change at the surface or near-surface of this terrestrial body. These changes raise questions about a decades-old paradigm, formed largely in the aftermath of very coarse Mariner-mission imagery in the 1960s, suggesting that much of the interesting geological activity on Mars occurred deep in its past, eons ago. The book includes discussions of Mars' ever-changing atmosphere and the impact of this on the planet's surface and near-surface; the possible involvement of water in relatively new, if not contemporary, gully-like flows and slope streaks (i.e., recurring slope lineae); and the identification of a broad suite of agents and processes (i.e., glacial, periglacial, aeolian, meteorological, volcanic, and meteoric) that are actively revising surface and near-surface landscapes, landforms, and features on a local, regional, and hemispheric scale. Highly illustrated and punctuated by data from the most recent Mars missions, *Dynamic Mars* is a valuable resource for all levels of research in the geological history of Mars, as well as of the three other terrestrial planets.

**Airless Bodies of the Inner Solar System: Understanding the Process Affecting Rocky, Airless Surfaces**
Elsevier, 2018, 293 pp., Paperback, $100.00. www.elsevier.com

*Airless Bodies of the Inner Solar System: Understanding the Process Affecting Rocky, Airless Surfaces* focuses on the airless, rocky bodies in the inner solar system as a host unto themselves, with a unique set of processes that require a specific set of investigative techniques. The book allows readers to understand both the basic and advanced concepts necessary to understand and employ that information. Topics cover past exploration of these surfaces, changes with time, space weathering, impact cratering, creation and evolution of regolith and soils, comparison of sample and remote sensing data, dust characterization, surface composition and thoughts for future exploration. Together the authors represent the unique combination of skills and experience required to produce an excellent book on the subject of the surfaces of airless, rocky bodies in the solar system, which will be useful both for graduate students and for working scientists.

**Mission Moon 3-D: A New Perspective on the Space Race**
MIT Press, 2018, 192 pp., Hardcover. $40.00. mitpress.mit.edu

July 2019 marks the fiftieth anniversary of Apollo 11’s epochal lunar landing, when Neil Armstrong and Buzz Aldrin walked on the surface of the Moon. This visually rich book offers a new perspective on that historic accomplishment, telling the story of the lunar landing and the events that led up to it with text and 3-D images. A 3-D viewer, designed by astrophysicist (and lead guitarist with the rock group Queen) Brian May is included with the book. *Mission Moon 3-D* offers unique access to the Apollo astronauts and what they saw. It tells the story of the US-Soviet space race, from Sputnik and the space dog Laika to Mercury, Gemini, and Apollo. In 1961, President John F. Kennedy declared that America would put a man on the Moon by the end of the decade. On July 20, 1969, Neil Armstrong guided the Eagle to a safe landing on the edge of the Moon’s Sea of Tranquility. President Richard Nixon told the astronauts, and the nation, that it was “the greatest week in the history of the world since the Creation.” *Mission Moon 3-D* recounts all this and more in memorable and visually stunning fashion.

**The NASA Archives: 60 Years in Space**
TASCHEN, 2019, 468 pp., Hardcover, $150.00. www.taschen.com

Throughout NASA’s 60-year history, images have played a central role. Who today is not familiar with the Hubble Space Telescope's mesmerizing views of the universe or the pin-sharp panoramas of Mars from NASA’s surface rovers? And who could forget the photographs of the first men walking on the Moon? Researched with the collaboration of NASA, this collection gathers more than 400 historic photographs and rare concept renderings, scanned and remastered using the latest technology and reproduced in extra-large size. Texts by science and technology journalist Piers Bizony, former NASA chief historian Roger Launius, and best-selling Apollo historian Andrew Chaikin — and an extensive mission checklist documenting the key human and robotic missions — round out this comprehensive exploration of NASA, from its earliest days to its current development of new space systems for the future. *The NASA Archives* is more than just a fascinating pictorial history of the U.S. space program. It is also a profound meditation on why we choose to explore space and how we will carry on this grandest of all adventures in the years to come.
This book introduces the reader to the wonders of Mars, covering all aspects from our past perceptions of the planet through to the latest knowledge on its history, its surface processes such as impact cratering, volcano formation, and glaciation, and its atmosphere and climate. In addition, a series of ten intriguing open issues are considered in a more advanced way. These include thought-provoking questions such as: What turned off the planet's magnetic field? Why are the northern and southern hemispheres so different? What was the fate of the once abundant water? Is there, or was there, life on Mars? Numerous original figures, unavailable elsewhere, reproduce details of images from Viking, CTX, MOC, HiRISE, THEMIS, and HRSC. *Mysteries of Mars* will appeal especially to general readers interested in planetary sciences, astronomy, astrogeology, and space exploration and to students of Earth Sciences and Natural and Environmental Sciences. The higher-level material on the remaining mysteries of Mars will also be of interest to astrogeologists and other researchers.

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The past few years have seen an incredible explosion in our knowledge of the universe. Since its 2009 launch, the Kepler satellite has discovered more than two thousand exoplanets, or planets outside our solar system. More exoplanets are being discovered all the time, and even more remarkable than the sheer number of exoplanets is their variety. In *Exoplanets*, astronomer Michael Summers and physicist James Trefil explore these remarkable recent discoveries: planets revolving around pulsars, planets made of diamond, planets that are mostly water, and numerous rogue planets wandering through the emptiness of space. This captivating book reveals the latest discoveries and argues that the incredible richness and complexity we are finding necessitates a change in our questions and mental paradigms. In short, we have to change how we think about the universe and our place in it because it is stranger and more interesting than we could have imagined.

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Do you dream of traveling to other worlds? This visually spectacular book brings you closer to an interplanetary voyage than ever before! Following in the footsteps of Jim Bell's successful *The Space Book*, *Mars 3-D*, and *Moon 3-D*, this large-format volume offers space enthusiasts an unparalleled visual experience of our solar system. Featuring eight removable NASA posters highlighting the wonders of space, gorgeous full-color photography, and stunning art, Bell's travel guide takes you on a futuristic tour of the solar system and beyond. Along the way, you'll experience what it's like to hike across lunar craters, soar through the winds of Venus, and raft down the rapids of Titan. Informative summaries of every destination are based on knowledge gleaned from more than 50 years of space exploration. The images provide a taste of the awe-inspiring destinations that we may one day reach, from the oceans of Europa to the newly discovered planets of TRAPPIST-1, while captions draw our attention to the unusual craters, ridges, seas, and storms captured by orbiting satellites, landers, and rovers.

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Narrated by Academy-Award-winner Jennifer Lawrence, *A Beautiful Planet* is a breathtaking portrait of Earth from space, providing a unique perspective and increased understanding of our planet and galaxy as never seen before. Made in cooperation with NASA, the film features stunning footage of our magnificent blue planet — and the effects humanity has had on it over time — captured by the astronauts aboard the International Space Station. From space, Earth blazes at night with the electric intensity of human expansion — a direct visualization of our changing world. But it is within our power to protect the planet. As we continue to explore and gain knowledge of our galaxy, we also develop a deeper connection to the place we all call home.

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This beautiful circular jigsaw puzzle is 18 inches (46 cm) in diameter. Viking 1 Orbiter imagery of Mars provides a vivid picture that is affixed to a strong cardboard backing, then die-cut to produce 350 puzzle pieces. The finished product can be coated with puzzle glue, framed, and displayed. Warning: Not suitable for children younger than 3 years. The puzzle's small pieces may pose a possible choking hazard.
Astronomy for Kids: How to Explore Outer Space with Binoculars, a Telescope, or Just Your Eyes!


One of the coolest things about outer space is that anyone can explore it. All you have to do is go outside and look up! Using plain sight, binoculars, or a small telescope, Astronomy for Kids shows stargazers how easy it is to explore space, just by stepping outside. With this book as their guide to the northern hemisphere, kids will learn to find and name amazing objects in the night sky. Fully illustrated with fun facts throughout, kids can point out sights to friends and family, saying things like, “that’s Jupiter,” and, “those stars are the constellation Cygnus the Swan,” and maybe even, “that group of stars doesn’t have a name but I think it looks like my dog getting belly rubs.” From the Milky Way Galaxy to Mars to the Moon’s craters and mountains, Astronomy for Kids helps young astronomers discover important parts of our solar system, with 30 sights for the naked eye, 25 sights magnified, and clear illustrations that show kids where to look and what they can expect to see. Like all big things, outer space is something you have to see to believe. Astronomy for Kids teaches kids that planets, shooting stars, constellations, and meteor showers are not only in books but right above them. For ages 7 to 13.

Space Discoveries

Capstone Press, 2018, 32 pp., Hardcover. $28.65. www.capstonepub.com

Imagine discovering new planets lightyears away or galaxies you never knew existed. Readers learn all about new and amazing space discoveries in these carefully-leveled and engaging books reviewed by Smithsonian experts. For ages 7 to 10.

Science Comics: Solar System – Our Place in Space


With Science Comics, you can explore the depths of the ocean, the farthest reaches of space, and everything in between! These gorgeously illustrated graphic novels offer wildly entertaining views of their subjects. In this volume, get up close and personal with Earth’s nearest neighbors—Venus with its acid rainstorms, Saturn and its rings of ice, and the heart of it all, the Sun. Humans have always been fascinated by outer space, and we're learning more about our solar system every day. Did you know that our solar system was born from a cloud of cosmic dust? That Jupiter’s red spot is really a raging storm? Join Sara, Jill, and their space-faring pets on a quest to learn more about the wonders of our Solar System—and beyond! For ages 9 to 13.
2019 Upcoming Events

January

Mars Extant Life: What's Next?
- January 29-1
- Carlsbad, New Mexico
- https://www.hou.usra.edu/meetings/lifeonmars2019/

February

XV Congresso Nazional de Scienze Planetarie
- February 4-8
- Florence, Italy
- http://www.iaps.inaf.it/attivita/convegni/planetologia/

PERC International Symposium on Dust and Parent Bodies 2019 (IDP2019)
- February 12-14
- Chiba, Japan

Thermal Models for Planetary Science III (TherMoPS III)
- February 20-22
- Budapest, Hungary

Lunar ISRU 2019 – Developing a New Space Economy Through Lunar Resources and Their Utilization
- February 20-22
- Columbia, Maryland
- https://www.hou.usra.edu/meetings/lunarisru2019/

4th International Conference On Atomic and Molecular Physics
- February 25-26
- Singapore
- https://www.meetingsint.com/conferences/molecularphysics

Workshop on In-Situ Exploration of the Ice Giants
- February 25-27
- Marseille, France
- https://icegiants2018.sciencesconf.org/

March

Kepler and K2 Science Conference V
- March 4-8
- Glendale, California
- https://keplerscience.arc.nasa.gov/scicon-2019

Centaur Exploration Workshop: The Roots of Activity
- March 6-8
- Orlando, Florida
- https://cew2019.arc.nasa.gov/

Large Surveys with Small Telescopes: Past, Present, and Future
- March 11-13
- Bamberg, Germany
- https://www.sternwarte.uni-erlangen.de/large-surveys-2019
Microsymposium 60: Forward to the Moon to Stay: Undertaking Transformative Lunar Science with Commercial Partners
- March 16-17
- The Woodlands, Texas
- [http://www.planetary.brown.edu/html_pages/micro60.htm](http://www.planetary.brown.edu/html_pages/micro60.htm)

50th Lunar and Planetary Science Conference
- March 18-22
- The Woodlands
- [https://www.hou.usra.edu/meetings/lpsc2019/](https://www.hou.usra.edu/meetings/lpsc2019/)

Life3E’2019: Search for Life, from Early Earth to Exoplanets
- March 25-29
- Quy Nhon, Vietnam
- [https://icisequynhon.com/conferences/2019/search-for-life/](https://icisequynhon.com/conferences/2019/search-for-life/)

NASEM’s Committee on Astrobiology and Planetary Science (CAPS)
- March 26-28
- Washington, D.C.
- [http://sites.nationalacademies.org/SSB/SSB_067577#Meetings_and_Events](http://sites.nationalacademies.org/SSB/SSB_067577#Meetings_and_Events)

New Quests in Stellar Astrophysics IV: Astrochemistry, Astrobiology, and the Origin of Life
- March 31-5
- Puerto Vallarta, Mexico
- [http://www.inaoep.mx/puerto19/](http://www.inaoep.mx/puerto19/)

April

The Space Astrophysics Landscape for the 2020s and Beyond
- April 1-3
- Potomac, Maryland
- [https://www.hou.usra.edu/meetings/landscape2019/](https://www.hou.usra.edu/meetings/landscape2019/)

2nd International Conference on Astronomy, Astrophysics, and Astrobiology
- April 4-6
- Auckland, New Zealand
- [https://astronomy.conferenceseries.com/](https://astronomy.conferenceseries.com/)

EGU General Assembly 2019
- April 7-12
- Vienna, Austria
- [https://www.egu2019.eu](https://www.egu2019.eu)

Better Stars, Better Planets: Exploiting the Stellar-Exoplanetary Synergy
- April 14-28
- Santa Barbara, California
- [https://www.kitp.ucsb.edu/activities/exostar19](https://www.kitp.ucsb.edu/activities/exostar19)

The 9th International Workshop on Occultation and Eclipse (IWOE9)
- April 16-17
- Dubai, United Arab Emirates
- [http://iota-me.com/oe.php](http://iota-me.com/oe.php)

4th Edition of International Conference on Advanced Spectroscopy, Crystallography, and Applications in Modern Chemistry
- April 25-26
- Rome, Italy
- [https://crystallography.euroscicon.com/](https://crystallography.euroscicon.com/)
2019 IAA Planetary Defense Conference (PDC)
- April 29-3
- Washington, DC
- http://pdc.iaaweb.org/

May
Applied Space Environments Conference
- May 12-17
- Los Angeles, California
- https://sti.usra.edu/ASEC2019/

ExoComets: Understanding the Composition of Planetary Building Blocks
- May 13-17
- Leiden, the Netherlands

New Horizons in Planetary Systems with ALMA
- May 13-17
- Victoria, Canada

The Human to Mars Summit
- May 14-16
- Washington, D.C.
- https://h2m.exploremars.org

2nd European Physics Congress
- May 20-21
- Berlin, Germany
- https://www.meetingsint.com/conferences/europhysics

Planet-Star Connections in the Era of TESS and Gaia
- May 20-24
- Santa Barbara, California
- https://www.kitp.ucsb.edu/activities/exostar-c19

European Lunar Symposium
- May 21-23
- Manchester, United Kingdom
- https://els2019.arc.nasa.gov

Ocean Worlds 4
- May 21-22
- Columbia, Maryland
- https://www.hou.usra.edu/meetings/oceanworlds2019/

Japanese Geoscience Union Meeting
- May 26-30
- Chiba, Japan
- http://www.jggu.org/meeting_e2019

3rd Advanced School on Exoplanetary Science: Demographics of Exoplanetary Systems
- May 27-31
- Vietri sul Mare, Italy
- http://www.mpio.de/ases3
June

Planetary Dynamics 2019

June 3-9
Heidelberg, Germany
http://www.mpia.de/homes/dynamics2019

The Main Belt: A Gateway to the Formation and Early Evolution of the Solar System

June 4-7
Villasimius, Sardinia, Italy
http://www.iaps.inaf.it/sz/mainbelt2019/

Planetary Exploration Horizon 2061: Synthesis Workshop

June 5-7
Toulouse, France
http://horizon2061.cnrs.fr/meetings-events/

234th Meeting of the American Astronomical Survey

June 9-13
St. Louis, Missouri
https://aas.org/meetings/aas234

Impacts and Their Role in the Evolution of Life

June 10-13
Tällberg, Siljan crater area, Sweden
http://www.nordicastrobiology.net/impacts2019

Zooming in on Star Formation

June 10-14
Nafplio, Greece
https://indico.nbi.ku.dk/event/1055/

50th Annual Meeting of the Division on Dynamical Astronomy (DDA) of the AAS

June 10-14
Boulder, Colorado
https://dda.aas.org/meetings/2019

10th Joint Meeting of The Space Resources Roundtable (SRR) and the Planetary and Terrestrial Mining Sciences Symposium (PTMSS)

June 11-14
Golden, Colorado
http://www.isruinfo.com/

TRAPPIST-1: Towards the Comparative Study of Temperate Terrestrial Worlds

June 11-14
Liege, Belgium
https://events.uliege.be/trappist-1/

Exoclimes Simulation Platform (ESP) Inaugural Summer School

June 12-14
Guarda Val, Switzerland
http://www.csh.unibe.ch/research/projects/exoclimes_simulation_platform/index_eng.html
3rd International Conference & Expo on Laser, Optics, & Photonics

- Date: June 14-15
- Location: London, UK
- Website: http://www.meetingsint.com/conferences/laser-optics

From Stars to Planets II — Connecting Our Understanding of Star and Planet Formation

- Date: June 17-20
- Location: Gothenburg, Sweden
- Website: http://cosmicorigins.space/fstpii

Emerging Researchers in Exoplanet Science (ERES)

- Date: June 17-19
- Location: Ithaca, New York

International Meeting on Paleoclimate: Changes and Adaptation

- Date: June 18-19
- Location: Coimbra, Portugal
- Website: https://paleoclimate2019.wixsite.com/paleoclimate2019

4th Planetary Data Workshop

- Date: June 18-20
- Location: Flagstaff, Arizona
- Website: https://www.hou.usra.edu/meetings/planetdata2019/

Royal Astronomical Society 2019 National Astronomy Meeting

- Date: June 20-4
- Location: Lancashire, England
- Website: https://nam2019.org

Meteoritical, Spacecraft and Astrophysical Perspectives on the Assembly and Composition of Planets

- Date: June 23-28
- Location: Mount Holyoke College, Massachusetts
- Website: https://www.grc.org/origins-of-solar-systems-conference/2019/

2019 Astrobiology Science Conference (AbSciCon)

- Date: June 24-28
- Location: Seattle, Washington
- Website: https://astrobiology.nasa.gov/news/absciicon-2019-save-the-date

The Planetary CubeSats Symposium

- Date: June 27-28
- Location: Goddard Space Flight Center, Greenbelt, Maryland
- Website: https://cubesats.gsfc.nasa.gov/symposium.php

July

International Planetary Probe Workshop 2019

- Date: July 8-12
- Location: Oxford, United Kingdom
- Website: https://ippw2019.uk/

Global Experts Meeting on Frontiers in Chemistry

- Date: July 11-19
- Location: London, England
- Website: https://frontiersmeetings.com/conferences/chemistry/
Pluto System After New Horizons

- July 14-18
- Laurel, Maryland
- [https://www.hou.usra.edu/meetings/plutosystem2019/](https://www.hou.usra.edu/meetings/plutosystem2019/)

Great Barriers in Planet Formation

- July 22-26
- Palm Cove, Australia

Ninth International Conference on Mars

- July 22-26
- Pasadena, California
- [https://www.hou.usra.edu/meetings/ninthmars2019/](https://www.hou.usra.edu/meetings/ninthmars2019/)

International Union for Quarternary Science Congress

- July 25-31
- Dublin, Ireland

NASA Exploration Science Forum

- July 26-28
- NASA Ames/Mountain View, California
- [https://nesf2018.arc.nasa.gov/](https://nesf2018.arc.nasa.gov/)

16th Annual Meeting of the Asia Oceania Geosciences Society (AOGS)

- July 28-2
- Singapore

TESS Science Conference I

- July 29-2
- Cambridge, Massachusetts

August

New Cometary Insights from the Close Approach of 46P/Wirtanen: A Symposium in Celebration of Mike A'Hearn

- August 6-8
- College Park, Maryland

Exoclimes V

- August 12-15
- Oxford, UK

Hot-Wiring the Transient Universe VI

- August 19-22
- Evanston, Illinois
- [http://hanksville.org/hotwired6/](http://hanksville.org/hotwired6/)

Extreme Solar Systems V

- August 19-23
- Reykjavik, Iceland
- [https://sites.northwestern.edu/iceland2019/](https://sites.northwestern.edu/iceland2019/)

September
### Habitability: Producing Conditions Conducive to Life
- **September 8-12**
- **Big Sky, Montana**
- [https://www.hou.usra.edu/meetings/habitability2019/](https://www.hou.usra.edu/meetings/habitability2019/)

### NASEM's Committee on Astrobiology and Planetary Science (CAPS)
- **September 10-12**
- **Irvine, California**
- [http://sites.nationalacademies.org/SSB/SSB_067577#Meetings_and_Events](http://sites.nationalacademies.org/SSB/SSB_067577#Meetings_and_Events)

### International Association of Sedimentologists Meeting
- **September 10-13**
- **Rome, Italy**
- [http://www.sedimentologists.org](http://www.sedimentologists.org)

### Physics of Stars and Planets: Atmospheres, Activity, Magnetic Fields
- **September 16-20**
- **Shamakhy, Azerbaijan**

### 2019 GSA Annual Meeting
- **September 22-25**
- **Phoenix, Arizona**
- [https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2019.aspx](https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2019.aspx)

### Large Meteorite Impacts and Planetary Evolution VI
- **September 30-3**
- **Brasilia, Brazil**
- [https://www.hou.usra.edu/meetings/lmi2019/](https://www.hou.usra.edu/meetings/lmi2019/)

### October
- **70th International Astronautical Congress (IAC)**
  - **October 21-25**
  - **Washington, DC**
  - [https://www.iac2019.org](https://www.iac2019.org)

### November
- **COSPAR 2019**
  - **November 4-8**
  - **Herzliya, Israel**

### December
- **First International Orbital Debris Conference (IOC)**
  - **December 9-12**
  - **Houston, Texas**
  - [https://www.hou.usra.edu/meetings/orbitaldebris2019/](https://www.hou.usra.edu/meetings/orbitaldebris2019/)