OSIRIS-REx is NASA’s third New Frontiers mission, following the New Horizons mission, which completed a flyby of Pluto in 2015, and the Juno mission to orbit Jupiter, which has just begun science operations. The OSIRIS-REx mission’s primary objective is to collect pristine surface samples of a carbonaceous asteroid and return them to Earth for analysis. Carbonaceous asteroids and comets are considered to be “primitive” bodies that have preserved remnants of the solar system starting materials. By studying them, scientists can learn about the origin and earliest evolution of the solar system. The OSIRIS-REx spacecraft was launched on September 8, 2016, beginning its two-year journey to asteroid 101955 Bennu (formerly designated 1999 RQ36). After more than one year of detailed remote observations, OSIRIS-REx will obtain surface samples and return them to Earth in September 2023.

The OSIRIS-REx proposal, led by the late Dr. Michael J. Drake, was selected during the 2011 New Frontiers competition, and is now led by Dr. Dante Lauretta of the University of Arizona. The mission name OSIRIS-REx (an acronym for Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) embodies five objectives: (1) Origins: Return and analyze a sample of a carbonaceous asteroid; (2) Spectral Interpretation: Provide ground truth for remote observations of asteroids; (3) Resource Identification: Determine the mineral and chemical makeup of a near-Earth asteroid; (4) Security: Directly measure the non-gravitational force known as the Yarkovsky effect, which changes asteroidal orbits through its interaction with sunlight; and (5) Regolith Explorer: Determine the properties of unconsolidated material that covers the asteroid surface.

Motivation for Sample Return

Much of our knowledge of the origin and evolution of the solar system has been gleaned from the study of meteorites that are pieces of asteroids. Some asteroids such as (4) Vesta (the target of the ongoing Dawn mission) were large enough to “differentiate,” caused by internal heating that separated metal from silicate rocks. Other asteroids were not as strongly heated but were mainly affected by aqueous alteration. Primitive meteorites, like the CM chondrite shown on page 3, are rare and
OSIRIS-REx Goes Asteroid Collecting continued...

OSIRIS-REx will return surface samples of the type of asteroid thought to be the parent body of the most primitive meteorites, carbonaceous chondrites. These asteroids are as dark as coal, suggesting that they are rich in carbon. Comparisons of the returned samples with meteorites and OSIRIS-REx’s remote observations of Bennu will help to identify the sources of primitive meteorites. The meteorite shown here is classified as a CM2 carbonaceous chondrite that was collected by the U.S.-led Antarctic Search for Meteorites (ANSMET) expedition to Antarctica in 1996.

Fragile but have remained largely unchanged in the 4.5 billion years since the planets in our solar system formed. Studies have revealed interstellar materials within some meteorites that pre-date the solar system, high-temperature minerals that condensed from the solar nebula, and complex organic matter that formed in space and within asteroids. Laboratory analyses of these materials have led to new insights into the inner workings of stars, chemical processes in the galaxy, and the initial stages of planet formation. Moreover, asteroids may have been important contributors of water and organic matter to Earth early in its history.

The science value of meteorite studies is great, but faces some serious limitations. One of the most important problems is that, with very few exceptions, the parent asteroids of meteorites are not known. It is not known which meteorites share the same parent body. This challenge is not wholly unlike a geologist being given a pile of rocks with no documentation of where they come from — or even what planet they come from — and being asked to construct their formation history and the origin of the solar system. Direct sample return from the surface of a well-characterized asteroid represents a whole new field of planetary science. Sample return makes it possible to connect global-scale observations and geological context with microscopic mineralogical and chemical properties. Together, these coordinated studies will bring a more complete understanding of how asteroids and the solar system formed and evolved.

Sample return can also circumvent the problem of terrestrial contamination that is particularly troublesome for studies of organic compounds. Most meteorites were recovered many years after they landed on Earth, and fresh meteorite “falls” sometimes occur in unfortunate locations such as farmland. Terrestrial weathering and contamination in our planet’s water- and organic-rich atmosphere quickly begin to take a toll on these precious samples as volatile materials are lost, minerals alter, and even terrestrial microorganisms take up residence. Of course, some of the most scientifically important organic compounds in meteorites are those that are common in biology, so it is not always possible to subtract out unknown contaminants from sample measurements. OSIRIS-REx will collect and return the most pristine samples of primitive asteroidal material ever available for study.

Finally, OSIRIS-REx will help to bridge the gap between remote spectroscopic studies of asteroids and the material properties of meteorites. Airless bodies like the Moon and asteroids are assaulted by radiation from the Sun and high-velocity impacts from interplanetary dust and larger bodies. These
“space weathering” processes change the spectral properties of asteroids, complicating comparisons with meteorites. The recent successful Japanese mission Hayabusa, which returned the first samples from near-Earth asteroid Itokawa, proved the value of asteroid sample return. Analyses of dozens of tiny dust particles returned to Earth confirmed a link between S-type asteroids and the most common type of meteorites: ordinary chondrites. But the spectra of asteroids thought to be the most primitive are not well understood and are practically featureless. The return of samples from well-characterized, primitive asteroids by OSIRIS-REx and the already-flying Japanese mission Hayabusa2 will provide valuable new insight into the nature of the most-distant and perhaps best-preserved asteroids.

Why Bennu?

The OSIRIS-REx mission had to select the best target out of over 500,000 known asteroids in the solar system, with thousands more being discovered every year. It might seem that the target selection would be an overwhelming task, but technical limitations and scientific motivation quickly narrowed the choices. Most asteroids orbit the Sun between 2.2 and 3.2 astronomical units (AU), where 1 AU is the distance from the Sun to Earth. But asteroids beyond 1.6 AU from the Sun are out of reach for the OSIRIS-REx spacecraft, since it relies upon solar power. Other asteroids within 0.8 AU of the Sun reside in a realm in which it is more difficult for spacecraft to operate, and are likely to have some of their most interesting organic and water-rich materials cooked away in the intense sunlight. To select from among the remaining 7000 near-Earth asteroids, we needed to find asteroids that are easy to reach and easy to return from. After rejecting asteroids with orbits inclined to Earth’s orbital plane, noncircular orbits, or retrograde orbits, we were left with 192 potential targets.

The OSIRIS-REx sampling strategy requires us to be able to “hover” over the target surface, so we rejected rapidly rotating asteroids. Most of the accessible asteroids are so small (<200 meters) that they rotate very quickly, as fast as 1 revolution per minute or along two axes (tumbling). Among the 26 candidates, 5 had spectral properties indicating they were carbonaceous asteroids. Bennu rises to the top of candidate asteroids — almost one in a million —
as being a very accessible, carbonaceous, well-studied asteroid.

Finally, Bennu is considered a hazardous asteroid, with an estimated 1-in-2700 chance of hitting Earth between the years 2175 and 2199. OSIRIS-REx observations will help to refine predictions of Bennu’s future orbit and revise impact probabilities. Global and microscale characterizations of Bennu will provide the information necessary to develop mitigation strategies and technology to protect our home planet from a potential impact.

The name Bennu was selected from more than eight thousand student entries from dozens of countries around the world who entered a “Name That Asteroid!” contest run by the University of Arizona, The Planetary Society, and the Lincoln Near Earth Asteroid Research (LINEAR) project. A third-grade student, Michael Puzio of North Carolina, proposed the name in reference to the Egyptian mythological bird Bennu, as he thought the spacecraft with its extended sample collection arm resembled the Egyptian deity, which is typically depicted as a heron.

Asteroid Bennu has a mean diameter of 492 meters (less than half a mile!), with a spheroidal, “spinning top” shape based on radar images. This is interpreted as a rubble-pile structure, where surface materials have gradually migrated to the equator. If this is true, then there is probably a lot of loose material on the surface suitable for sampling. Reflectance spectroscopy of Bennu show it is very dark, with an albedo of only 3–5%. It is classified as a B-type asteroid, like the asteroid Themis, and is thought to have hydrated materials on its surface and abundant carbonaceous material. The closest meteorite analogs are the very rare CI and CM chondrites like Orgueil and Murchison, which are rich in hydrated minerals like clays and organic matter. These types of meteorites are very primitive and contain materials from the birth of the solar system, including the first generation condensates from the solar nebula, organic matter formed within the parent asteroid and interstellar clouds, and micrometer-sized grains of stardust.

**Surveying Bennu**

After arriving at asteroid Bennu, the OSIRIS-REx spacecraft will spend more than a year mapping surface structures, boulder and crater distributions, three-dimensional shape, gravity field, mineralogy, chemistry, and surface temperatures in order to thoroughly characterize the global geology of the asteroid and guide the selection of the sampling site. Four top-level maps will be produced to guide the sample site selection:
OSIRIS-REx Goes Asteroid Collecting continued...

- **Safety:** Asteroid surfaces pose various hazards for spacecraft, such as irregular slopes, boulders, and complex gravity fields. The team will consider these factors to identify no-go areas of Bennu that are unsafe for sample collection.

- **Deliverability:** This map will quantify how well the spacecraft can be navigated to the sample site. Asteroid Bennu will be so far from Earth that it will not be possible to fly the spacecraft remotely in real time, so the flight to the sample site will have to be done autonomously. Some areas of the asteroid may be too difficult to reach accurately unguided, especially in gravitationally or topographically complex areas.

- **Sampling ability:** OSIRIS-REx is designed to collect loose regolith: unconsolidated dust and rocks less than 2 centimeters in size. The remote surveys and detailed high-resolution images will be used to find areas that are suitable for satisfying the mission requirement to collect at least 60 grams of material.

- **Science value:** All areas of the asteroid surface are scientifically valuable, but the scientific priorities of OSIRIS-REx are the study of organic materials, water-rich phases, and presolar grains. The science value map will quantify the spectral evidence for various kinds of minerals and organic phases as well as the surface geology and temperatures in order to identify the area on the asteroid that is most likely to satisfy this mission priority.

The OSIRIS-REx payload includes several instruments, which will be used to observe and characterize Bennu to generate the sample selection maps and for basic navigation. The OSIRIS-REx Camera Suite (OCAMS) is made up of three cameras that will perform low-resolution, long-range imaging, global mapping and imaging of the actual sampling site down to 1-centimeter spatial resolution. The OSIRIS-REx Laser Altimeter (OLA) is a scanning laser rangefinder that will be used to make a three-dimensional topographic map of the entire asteroid. Higher-resolution three-dimensional maps will be taken of candidate sampling sites. The OSIRIS-REx Visible and Infrared Spectrometer (OVIRS) observes reflected light in the visible and near-infrared parts of the spectrum, in which characteristic absorption bands of the rock-forming minerals occur. The OSIRIS-REx Thermal Emission Spectrometer (OTES) is sensitive to longer infrared wavelengths, which contain information on both mineralogy and physical properties. Together, OVIRS and OTES will be used to map the abundance and distribution of organics and various minerals such as silicates, oxides, carbonates, and sulfates. The Regolith X-ray Imaging Spectrometer (REXIS) — a collaboration experiment developed by students from the Massachusetts Institute of Technology — is an X-ray imaging system that will develop a map of the elemental abundances on Bennu by measuring the fluorescent X-rays induced by sunlight and emitted from the asteroid surface.
**Touch-and-Go Sampling**

The Touch-And-Go Sample Acquisition Mechanism (TAGSAM) is an aluminum and stainless steel cylinder about the diameter of a dinner plate mounted at the end of a long arm equipped with a strong spring like a pogo stick. The actual sample collection is relatively simple and will be over in just a few seconds. The spacecraft will slowly approach the sampling site with its sampling arm outstretched. Once pressure sensors detect surface contact, high-pressure ultra-pure nitrogen gas will be jetted into the regolith to mobilize it, directing rocks and dust into the collector like a reverse vacuum. A separate sample of fine-grained dust will be collected with stainless steel Velcro independent of the bulk-gas-mobilized sample. After five seconds, the spacecraft will retreat. Once the spacecraft has safely backed away, it will be rotated with its TAGSAM outstretched to measure the amount of mass collected. If it is determined that too little mass was collected, the spacecraft can support two more sampling attempts. Numerous ground-based tests and even tests onboard the microgravity “vomit comet” high-altitude aircraft show that the sampler is very effective and can collect as much as 1 kilogram (35 ounces) of material, an amount well in excess of the OSIRIS-REx mission requirement.

**Coordinated Sample Studies**

After verifying a successful surface sampling in July 2020, OSIRIS-REx will stow the sample in the Sample Return Capsule (SRC) for the journey home. OSIRIS-REx will fire its engines to start the return cruise in March 2023, returning to Earth in September 2023. Upon approach, the spacecraft will release the SRC for a fiery flight through Earth’s atmosphere at 12.4 kilometers per second (27,738 miles per hour). The heat shield will absorb more than 99% of this kinetic energy. After an ~3-kilometer (1.9-mile) free-fall, the SRC will deploy two parachutes to slow the descent and allow for a gentle landing at the Utah Test and Training Range (UTTR). The SRC will then be transported to NASA’s Johnson Space Center in Houston, where the samples will be initially examined and permanently curated and made available for study by investigators around the world.
The OSIRIS-REx science team will examine the returned samples to understand Bennu’s entire formation history in distinct astrophysical epochs. Bennu’s history began with the presolar epoch, as dust grains formed in the outflows of evolved stars and supernovae and complex chemistry took place in molecular clouds. This was followed by the nebular epoch, as grains condensed and aggregated to form planetesimals in the early solar system. We will examine the early geological history of Bennu, the later surface regolith processes, and finally its dynamical evolution over the “most recent” millions of years to its present orbit and configuration. The sample studies will be focused on addressing specific hypotheses, such as whether or not Bennu is related to known meteorites, or whether it contains abundant grains of stardust that predate the origin of the solar system. Specific study objectives include measuring the ages of individual, microscopic mineral grains; characterizing aqueous phases and how and when they formed; and identifying any prebiotic organic molecules and their formation processes.

From the Bennu samples, we will determine their mineralogy and petrology, elemental and isotopic compositions, organic chemistry, spectral properties, and thermal properties. These studies will be carried out with a range of sophisticated instruments such as transmission electron microscopy (TEM), electron microprobe, ion microprobe, infrared spectroscopy, liquid and gas chromatography, synchrotron particle accelerators, and laser ionization mass spectrometry. One of the challenges the team will face is to perform as many different types of analyses as possible with the same starting materials. Such coordinated analyses save sample mass and also benefit science by making it possible to link different properties together.

Another important objective of our studies will be to link the spectral and material properties of surface regolith grains with the remote observations of Bennu as a whole and from the sampling site. Reflectance spectra of Bennu samples measured in the laboratory will be compared with remote astronomical spectra of asteroids. Space exposure histories will be studied by measuring gas implanted from the solar wind and by the radiation damage from the Sun and galactic cosmic rays. The technique of TEM is capable of revealing radiation damage at the atomic scales, including the approximate energies and total dose of the radiation. By linking the remote astronomical observations of Bennu, the OSIRIS-REx remote sensing campaign, and the laboratory studies of returned samples, scientists hope to gain new insights into the properties and origins of thousands of asteroids throughout the solar system that remain mere points of light.

For more information about the OSIRIS-REx mission, visit the mission website at http://asteroidmission.org or the blog of the mission’s principal investigator at http://dslauretta.com.
OSIRIS-REx Goes Asteroid Collecting continued . . .

About the Author:

Scott Messenger, a scientist in the Astromaterials Research and Exploration Science (ARES) division of the NASA Johnson Space Center in Houston, Texas, is a co-investigator on the OSIRIS-REx mission. As lead of the Sample Analysis Working Group for the mission, Messenger is in charge of contamination knowledge studies of flight hardware to ensure the integrity of the collected samples. Messenger is also responsible for developing a coordinated sample analysis plan of the returned samples, and will study the isotopic properties of the asteroidal samples with a NanoSIMS ion microprobe, a powerful mass spectrometer for measuring isotopic compositions of microscopic samples. He will determine the age of the samples and study the properties of ancient stardust grains and organic matter that predate the origin of the solar system.

Messenger received a B.S. in Astronomy and Physics from the University of Washington (1991) and a Ph.D. in Physics from Washington University in Saint Louis (1997). He joined NASA in 2003. His expertise is in isotopic analyses of extraterrestrial materials by secondary ion mass spectrometry (SIMS). His research interests include the nature and origin of materials in the solar nebula and preserved interstellar matter and stardust from comets and meteorites, and works closely with other researchers at ARES to coordinate isotopic studies with mineralogical studies by transmission electron microscopy and organic analyses by resonance ionization mass spectrometry and other spectroscopic techniques. He also took part in the analysis of cometary dust returned by the Stardust spacecraft in 2006.

About the Cover:

Top: A United Launch Alliance Atlas V rocket lifts off from Space Launch Complex 41 at Cape Canaveral Air Force Station, carrying NASA’s OSIRIS-REx spacecraft on the first U.S. mission to sample an asteroid. Liftoff was at 7:05 p.m. U.S. Eastern Daylight Time on Thursday, September 8. Credit: NASA/Sandy Joseph and Tim Terry.

Bottom left: The high-gain antenna and solar arrays were installed on the OSIRIS-REx spacecraft before it was moved to environmental testing in October. Credit: Lockheed Martin Corporation.

Bottom right: Artist’s concept of the OSIRIS-REx spacecraft near asteroid Bennu. Credit: NASA.
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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NASA Extends New Horizons and Other Planetary Missions

Following its historic first-ever flyby of Pluto, NASA’s New Horizons mission has received the green light to fly onward to an object deeper in the Kuiper belt, known as 2014 MU69. The spacecraft’s planned rendezvous with the ancient object — considered one of the early building blocks of the solar system — is January 1, 2019. “The New Horizons mission to Pluto exceeded our expectations, and even today the data from the spacecraft continue to surprise,” said NASA’s Director of Planetary Science, Jim Green. “We’re excited to continue onward into the dark depths of the outer solar system to a science target that wasn’t even discovered when the spacecraft launched.”

Based upon the 2016 Planetary Mission Senior Review Panel report, NASA directed nine extended missions to plan for continued operations through fiscal years 2017 and 2018. Final decisions on mission extensions are contingent on the outcome of the annual budget process. In addition to the extension of the New Horizons mission, NASA determined that the Dawn spacecraft should remain at the dwarf planet Ceres, rather than changing course to the main belt asteroid Adeona.

Green noted that NASA relies on the scientific assessment by the Senior Review Panel in making its decision on which extended mission option to approve. “The long-term monitoring of Ceres, particularly as it gets closer to perihelion (the part of its orbit with the shortest distance to the Sun) has the potential to provide more significant science discoveries than a flyby of Adeona,” he said.

Also receiving NASA approval for mission extensions are the Mars Reconnaissance Orbiter (MRO), Mars Atmosphere and Volatile Evolution (MAVEN), the Opportunity and Curiosity Mars rovers, the Mars Odyssey orbiter, the Lunar Reconnaissance Orbiter (LRO), and NASA’s support for the European Space Agency’s Mars Express mission.
Philae Comet Lander Found!

Less than a month before the end of the mission, Rosetta’s high-resolution camera has revealed the Philae lander wedged into a dark crack on Comet 67P/Churyumov-Gerasimenko. The images were taken on September 2 by the Optical, Spectral, and Infrared Remote Imaging System (OSIRIS) narrow-angle camera as the orbiter came within 2.7 kilometers (1.68 miles) of the surface and clearly show the main body of the lander, along with two of its three legs. The images also provide proof of Philae’s orientation, making it clear why establishing communications was so difficult following its landing on November 12, 2014.

“With only a month left of the Rosetta mission, we are so happy to have finally imaged Philae, and to see it in such amazing detail,” says Cecilia Tubiana of the OSIRIS camera team, the first person to see the images when they were downlinked from Rosetta on September 4. “After months of work, with the focus and the evidence pointing more and more to this lander candidate, I’m very excited and thrilled that we finally have this all-important picture of Philae sitting in Abydos,” added the European Space Agency’s (ESA’s) Laurence O’Rourke, who has been coordinating the search efforts over the last months at ESA, with the OSIRIS and Science Operations and Navigation Center (SONC)/Centre National d’Études Spatiales (CNES) teams.

Philae was last seen when it first touched down at Agilkia, bounced and then flew for another two hours before ending up at a location later named Abydos, on the comet’s smaller lobe. After three days, Philae’s primary battery was exhausted and the lander went into hibernation, only to wake up again and communicate briefly with Rosetta in June and July 2015 as the comet came closer to the Sun and more power was available.

However, until today, the precise location was not known. Radio ranging data tied its location down to an area spanning a few tens of meters, but a number of potential candidate objects identified in relatively low-resolution images taken from larger distances could not be analyzed in detail until recently. While most candidates were discarded from analysis of the imagery and other techniques, evidence continued to build toward one particular target, which is now confirmed in images taken unprecedentedly close to the surface of the comet. At 2.7 kilometers (1.68 miles), the resolution of the OSIRIS narrow-angle camera is about 5 centimeters/pixel (2 inches/pixel), sufficient to reveal characteristic features of Philae’s 1-meter-sized (3.3-foot-sized) body and its legs.

“This remarkable discovery comes at the end of a long, painstaking search,” says Patrick Martin, ESA’s Rosetta Mission Manager. “We were beginning to think that Philae would remain lost forever. It is incredible we have captured this at the final hour.”
“This wonderful news means that we now have the missing ‘ground-truth’ information needed to put Philae’s three days of science into proper context, now that we know where that ground actually is!” says Matt Taylor, ESA’s Rosetta project scientist.

The discovery comes less than a month before Rosetta descends to the comet’s surface. On September 30, the orbiter will be sent on a final one-way mission to investigate the comet from close up, including the open pits in the Ma’at region, where it is hoped that critical observations will help to reveal secrets of the body’s interior structure (see the following article).

For more information, visit http://www.esa.int/Our_Activities/Space_Science/Rosetta or http://rosetta.jpl.nasa.gov/.

Rosetta Finale Set for September 30

Rosetta is set to complete its mission in a controlled descent to the surface of its comet on September 30. The mission is coming to an end as a result of the spacecraft’s ever-increasing distance from the Sun and Earth. It is heading out toward the orbit of Jupiter, resulting in significantly reduced solar power to operate the craft and its instruments, and a reduction in bandwidth available to downlink scientific data. Combined with an aging spacecraft and payload that have endured the harsh environment of space for over 12 years — not least 2 years close to a dusty comet — this means that Rosetta is reaching the end of its natural life.

Unlike in 2011, when Rosetta was put into a 31-month hibernation for the most distant part of its journey, this time it is riding alongside the comet. Comet 67P/Churyumov-Gerasimenko’s maximum distance from the Sun (more than 850 million kilometers, or 528 million miles) is more than Rosetta has ever journeyed before. The result is that there is not enough power at its most distant point to guarantee that Rosetta’s heaters would be able to keep it warm enough to survive. Instead of risking a much longer hibernation that is unlikely to be survivable, and after consultation with Rosetta’s science team in 2014, it was decided that Rosetta would follow its lander Philae onto the comet.

The final hours of descent will enable Rosetta to make many once-in-a-lifetime measurements, including very-high-resolution imaging, boosting Rosetta’s science return with precious close-up data achievable
only through such a unique conclusion. Communications will cease, however, once the orbiter reaches the surface, and its operations will then end.

“We’re trying to squeeze as many observations in as possible before we run out of solar power,” says Matt Taylor, ESA Rosetta project scientist. “30 September will mark the end of spacecraft operations, but the beginning of the phase where the full focus of the teams will be on science. That is what the Rosetta mission was launched for, and we have years of work ahead of us, thoroughly analyzing its data.”

Rosetta’s operators began changing the trajectory in August ahead of the grand finale such that a series of elliptical orbits will take it progressively nearer to the comet at its closest point. “Planning this phase is in fact far more complex than it was for Philae’s landing,” says Sylvain Lodiot, ESA Rosetta spacecraft operations manager. “The last six weeks will be particularly challenging as we fly eccentric orbits around the comet — in many ways this will be even riskier than the final descent itself. The closer we get to the comet, the more influence its non-uniform gravity will have, requiring us to have more control on the trajectory, and therefore more maneuvers — our planning cycles will have to be executed on much shorter timescales.”

A number of dedicated maneuvers in the closing days of the mission will conclude with one final trajectory change at a distance of around 20 kilometers (12 miles) about 12 hours before impact, to put the spacecraft on its final descent. The region to be targeted for Rosetta’s impact is still under discussion, as spacecraft operators and scientists examine the various trade-offs involved, with several different trajectories being examined. Broadly speaking, however, it is expected that impact will take place at about 50 centimeters/second (1.6 feet/second), roughly half the landing speed of Philae in November 2014.

Commands uploaded in the days before will automatically ensure that the transmitter as well as all attitude and orbit control units and instruments are switched off upon impact, to fulfill spacecraft disposal requirements. In any case, Rosetta’s high-gain antenna will very likely no longer be pointing toward Earth following impact, making any potential communications virtually impossible.

In the meantime, science will continue as normal, although there are still many risks ahead. Last month, the spacecraft experienced a “safe mode” while only 5 kilometers (3 miles) from the comet as a result of dust confusing the navigation system. Rosetta recovered, but the mission team cannot rule out this happening again before the planned end of the mission.

“Although we’ll do the best job possible to keep Rosetta safe until then, we know from our experience of nearly two years at the comet that things may not go quite as we plan and, as always, we have to be prepared for the unexpected,” cautions Martin. “This is the ultimate challenge for our teams and for our spacecraft, and it will be a very fitting way to end the incredible and successful Rosetta mission.”
NASA’s Juno Successfully Completes Jupiter Flyby

NASA’s Juno mission successfully executed its first of 36 orbital flybys of Jupiter on August 27. The time of closest approach with the gas-giant world was 6:44 a.m. U.S. Pacific Daylight Time (13:44 UTC) when Juno passed about 4200 kilometers (2600 miles) above Jupiter’s swirling clouds. At the time, Juno was traveling at 208,000 kilometers per hour (130,000 miles per hour) with respect to the planet. This flyby was the closest Juno will get to Jupiter during its prime mission.

There are 35 more close flybys of Jupiter planned during Juno’s mission (scheduled to end in February 2018). The August 27 flyby was the first time Juno had its entire suite of science instruments activated and looking at the giant planet as the spacecraft zoomed past. “We are getting some intriguing early data returns as we speak,” said Scott Bolton, principal investigator of Juno from the Southwest Research Institute in San Antonio. “It will take days for all the science data collected during the flyby to be downlinked and even more to begin to comprehend what Juno and Jupiter are trying to tell us.”

While results from the spacecraft’s suite of instruments will be released down the road, a handful of images from Juno’s visible light imager, JunoCam, have already been released. Those images included the highest-resolution views of the jovian aurorae and the first glimpse of Jupiter’s north and south poles. “We are in an orbit nobody has ever been in before, and these images give us a whole new perspective on this gas-giant world,” said Bolton.

For more information, visit http://www.nasa.gov/juno or http://www.missionjuno.swri.edu.
Dawn Maps Ceres Craters Where Ice Can Accumulate

Scientists with NASA’s Dawn mission have identified permanently shadowed regions on the dwarf planet Ceres. Most of these areas likely have been cold enough to trap water ice for a billion years, suggesting that ice deposits could exist there now. “The conditions on Ceres are right for accumulating deposits of water ice,” said Norbert Schorghofer, a Dawn guest investigator at the University of Hawaii at Manoa. “Ceres has just enough mass to hold on to water molecules, and the permanently shadowed regions we identified are extremely cold — colder than most that exist on the Moon or Mercury.”

Permanently shadowed regions do not receive direct sunlight. They are typically located on the crater floor or along a section of the crater wall facing toward the pole. The regions still receive indirect sunlight, but if the temperature stays below about –151°C (–240°F), the permanently shadowed area is a cold trap — a good place for water ice to accumulate and remain stable. Cold traps were predicted for Ceres but had not been identified until now.

In this study, Schorghofer and colleagues studied Ceres’ northern hemisphere, which was better illuminated than the south. Images from Dawn’s cameras were combined to yield the dwarf planet’s shape, showing craters, plains, and other features in three dimensions. Using this input, a sophisticated computer model developed at NASA’s Goddard Space Flight Center was used to determine which areas receive direct sunlight, how much solar radiation reaches the surface, and how the conditions change over the course of a year on Ceres.

The researchers found dozens of sizeable permanently shadowed regions across the northern hemisphere. The largest one is inside a 16-kilometer-wide (10-mile-wide) crater located less than 65 kilometers (40 miles) from the north pole. Taken together, Ceres’ permanently shadowed regions occupy about 1800 square kilometers (695 square miles). This is a small fraction of the landscape — much less than 1% of the surface area of the northern hemisphere.

The team expects the permanently shadowed regions on Ceres to be colder than those on Mercury or the Moon. That’s because Ceres is quite far from the Sun, and the shadowed parts of its craters receive little indirect radiation. “On Ceres, these regions act as cold traps down to relatively low latitudes,” said Erwan Mazarico, a Dawn guest investigator at Goddard. “On the Moon and Mercury, only the permanently shadowed regions very close to the poles get cold enough for ice to be stable on the surface.”

The situation on Ceres is more similar to that on Mercury than the Moon. On Mercury, permanently shadowed regions account for roughly the same fraction of the northern hemisphere. The trapping efficiency — the ability to accumulate water ice — is also comparable.
News from Space continued...

By the team’s calculations, about 1 out of every 1000 water molecules generated on the surface of Ceres will end up in a cold trap during a year on Ceres (1682 days). That’s enough to build up thin but detectable ice deposits over 100,000 years or so. “While cold traps may provide surface deposits of water ice as have been seen at the Moon and Mercury, Ceres may have been formed with a relatively greater reservoir of water,” said Chris Russell, principal investigator of the Dawn mission, based at the University of California, Los Angeles. “Some observations indicate Ceres may be a volatile-rich world that is not dependent on current-day external sources.”

The findings are available online in the journal Geophysical Research Letters. For more information, visit http://dawn.jpl.nasa.gov or http://www.nasa.gov/dawn.

What’s Inside Ceres? New Findings from Gravity Data

In the tens of thousands of photos returned by NASA’s Dawn spacecraft, the interior of Ceres isn’t visible. However, scientists have powerful data to study Ceres’ inner structure — Dawn’s own motion. Since gravity dominates Dawn’s orbit at Ceres, scientists can measure variations in Ceres’ gravity by tracking subtle changes in the motion of the spacecraft.

Using data from Dawn, scientists have mapped the variations in Ceres’ gravity for the first time in a new study in the journal Nature, which provides clues to the dwarf planet’s internal structure.

“The new data suggest that Ceres has a weak interior, and that water and other light materials partially separated from rock during a heating phase early in its history,” said Ryan Park, the study’s lead author and the supervisor of the solar system dynamics group at NASA’s Jet Propulsion Laboratory (JPL).

Ceres’ gravity field is measured by monitoring radio signals sent to Dawn, and then received on Earth by NASA’s Deep Space Network. This network is a collection of large antennas at three locations around the globe that communicate with interplanetary spacecraft. Using these signals, scientists can measure the spacecraft’s speed to a precision of 0.1 millimeters (0.004 inches) per second, and then calculate the details of the gravity field.

Ceres has a special property called “hydrostatic equilibrium,” which was confirmed in this study. This means that Ceres’ interior is weak enough that its shape is governed by how it rotates. Scientists reached this conclusion by comparing Ceres’ gravity field to its shape. Ceres’ hydrostatic equilibrium is one reason why astronomers classified the body as a dwarf planet in 2006.
The data indicate that Ceres is “differentiated,” which means that it has compositionally distinct layers at different depths, with the densest layer at the core. Scientists also have found that, as they suspected, Ceres is much less dense than Earth, the Moon, the giant asteroid Vesta (Dawn’s previous target), and other rocky bodies in our solar system. Additionally, Ceres has long been suspected to contain low-density materials such as water ice, which the study shows separated from the rocky material and rose to the outer layer along with other light materials. “We have found that the divisions between different layers are less pronounced inside Ceres than the Moon and other planets in our solar system,” Park said. “Earth, with its metallic core, semi-fluid mantle, and outer crust, has a more clearly defined structure than Ceres,” Park said.

Scientists also found that high-elevation areas on Ceres displace mass in the interior. This is analogous to how a boat floats on water: The amount of displaced water depends on the mass of the boat. Similarly, scientists conclude that Ceres’ weak mantle can be pushed aside by the mass of mountains and other high topography in the outermost layer as though the high-elevation areas “float” on the material below. This phenomenon has been observed on other planets, including Earth, but this study is the first to confirm it at Ceres.

The internal density structure, based on the new gravity data, teaches scientists about what internal processes could have occurred during the early history of Ceres. By combining this new information with previous data from Dawn about Ceres’ surface composition, they can reconstruct that history: Water must have been mobile in the ancient subsurface, but the interior did not heat up to the temperatures at which silicates melt and a metallic core forms. “We know from previous Dawn studies that there must have been interactions between water and rock inside Ceres,” said Carol Raymond, a co-author and Dawn’s deputy principal investigator based at JPL. “That, combined with the new density structure, tells us that Ceres experienced a complex thermal history.”

After studying Ceres for more than eight months from its low-altitude science orbit, NASA’s Dawn spacecraft is now moving higher up for different views of the dwarf planet. Dawn has delivered a wealth of images and other data from its current perch at 385 kilometers (240 miles) above Ceres’ surface, which is closer to the dwarf planet than the International Space Station is to Earth. Now, the mission team is pivoting to consider science questions that can be examined from higher up.

After Dawn completed its prime mission on June 30, having surpassed all of its scientific objectives at Vesta and at Ceres, NASA extended the mission to perform new studies of Ceres. One of the factors limiting Dawn’s lifetime is the amount of hydrazine, the propellant needed to orient the spacecraft to observe Ceres and communicate with Earth. By going to a higher orbit at Ceres, Dawn will use the remaining hydrazine more sparingly, because it won’t have to work as hard to counter Ceres’ gravitational pull.

On September 2, Dawn began spiraling upward to about 1460 kilometers (910 miles) from Ceres. The altitude will be close to where Dawn was a year ago, but the orientation of the spacecraft’s orbit — specifically, the angle between the orbit plane and the Sun — will be different this time, so the spacecraft will have a different view of the surface.
ESO Discovers Earth-Sized Planet in Habitable Zone of Nearest Star

A newly discovered, roughly Earth-sized planet orbiting our nearest neighboring star might be habitable, according to a team of astronomers using the European Southern Observatory’s (ESO’s) 3.6-meter (11.8-foot) telescope at La Silla, Chile, along with other telescopes around the world. The exoplanet is at a distance from its star that allows temperatures mild enough for liquid water to pool on its surface.

“NASA congratulates ESO on the discovery of this intriguing planet that has captured the hopes and the imagination of the world,” says Paul Hertz, Astrophysics Division Director at NASA Headquarters. “We look forward to learning more about the planet, whether it holds ingredients that could make it suitable for life.”

The new planet circles Proxima Centauri, the smallest member of a triple star system known to science fiction fans everywhere as Alpha Centauri. Just over 4 light-years away, Proxima is the closest star to Earth, besides our own Sun. “This is really a game-changer in our field,” said Olivier Guyon, a planet-hunting affiliate at NASA’s Jet Propulsion Laboratory (JPL), and associate professor at the University of Arizona, Tucson. “The closest star to us has a possible rocky planet in the habitable zone. That’s a huge deal. It also boosts the already existing, mounting body of evidence that such planets are near, and that several of them are probably sitting quite close to us. This is extremely exciting.”

The science team that made the discovery, led by Guillem Anglada-Escudé of Queen Mary University of London, published its findings on August 25 in the journal *Nature*. The team traced subtle wobbles in the star, revealing the presence of a star-tugging planet.

They determined that the new planet, dubbed Proxima b, is at least 1.3 times the mass of Earth. It orbits its star far more closely than Mercury orbits our Sun, taking only 11 days to complete a single orbit — a “year” on Proxima b. The stunning announcement comes with plenty of caveats. While the new planet lies within its star’s “habitable zone” — a distance at which temperatures are right for liquid water — scientists do not yet know if the planet has an atmosphere.

It also orbits a red-dwarf star, far smaller and cooler than our Sun. The planet likely presents only one face to its star, as the Moon does to Earth, instead of rotating through our familiar days and nights. And Proxima b could be subject to potentially life-extinguishing stellar flares.

“That’s the worry in terms of habitability,” said Scott Gaudi, an astronomy professor at Ohio State University, Columbus, and JPL affiliate credited with numerous exoplanet discoveries. “This thing
is being bombarded by a fair amount of high-energy radiation. It’s not obvious if it’s going to have a magnetic field strong enough to prevent its whole atmosphere from getting blown away. But those are really hard calculations, and I certainly wouldn’t put my money either way on that.”

Despite the unknowns, the discovery was hailed by NASA exoplanet hunters as a major milestone on the road to finding other possible life-bearing worlds within our stellar neighborhood. “It definitely gives us something to be excited about,” said Sara Seager, a planetary science and physics professor at the Massachusetts Institute of Technology, Cambridge, and an exoplanet-hunting pioneer. “I think it will definitely motivate people to get moving.” Statistical surveys of exoplanets — planets orbiting other stars — by NASA’s Kepler space telescope have revealed a large proportion of small planets around small stars, she said.

The Kepler data suggest we should expect at least one potentially habitable, Earth-sized planet orbiting M-type stars, like Proxima, within 10 light-years of our solar system. So the latest discovery was “not completely unexpected. We’re more lucky than surprised,” Seager said. But it “helps buoy our confidence that planets are everywhere.”

It’s especially encouraging for upcoming space telescopes, which can contribute to the study of the new planet. The James Webb Space Telescope, launching in 2018, may be able to follow up on this planet with spectroscopy to determine the contents of its atmosphere. NASA’s Transiting Exoplanet Survey Satellite (TESS) will find similar planets in the habitable zone in the stellar backyard of our solar system in 2018. One of TESS’ goals is to find planets orbiting nearby M-dwarf stars like Proxima Centauri.

“It’s great news just to know that M-dwarf planets could be as common as we think they are,” Seager said. Another possible inspiration Proxima b could reignite: the admittedly far-off goal of sending a probe to another solar system.

Bill Borucki, an exoplanet pioneer, said the new discovery might inspire more interstellar research, especially if Proxima b proves to have an atmosphere. Coming generations of space- and groundbased telescopes, including large groundbased telescopes now under construction, could yield more information about the planet, perhaps inspiring ideas on how to pay it a visit.

“It may be that the first time we get really good information is from the newer telescopes that may be coming online in a decade or two,” said Borucki, now retired, the former principal investigator for Kepler, which has discovered the bulk of the more than 3300 exoplanets found so far. “Maybe people will talk about sending a probe to that star system,” Borucki said. “I think it does provide some inspiration for an interstellar mission because now we know there is a planet in the habitable zone, probably around the mass of Earth, around the closest star. I think it does inspire a future effort to go there and check it out.”

For more information, visit https://exoplanets.nasa.gov/.
Pluto’s Methane Snowcaps on the Edge of Darkness

The southernmost part of Pluto that NASA’s New Horizons spacecraft could “see” during closest approach in July 2015 contains a range of fascinating geological features, and offers clues into what might lurk in the regions shrouded in darkness during the flyby. The area shown is south of Pluto’s dark equatorial band informally named Cthulhu Regio, and southwest of the vast nitrogen ice plains informally named Sputnik Planum or Sputnik Planitia, as the mission team recently redesignated the area to more accurately reflect the low elevation of the plains. North is at the top; in the western portion of the image, a chain of bright mountains extends north into Cthulhu Regio.

The mountains reveal themselves as snowcapped — something hauntingly familiar because of our Earth-based experience. However, New Horizons compositional data indicate the bright snowcap material covering these mountains isn’t water, but atmospheric methane that has condensed as frost onto these surfaces at high elevation. Between some mountains are sharply cut valleys, which are each a few miles across and tens of miles long.

A similar valley system in the expansive plains to the east appears to be branched, with smaller valleys leading into it. New Horizons scientists think flowing nitrogen ice that once covered this area — perhaps when the ice in Sputnik was at a higher elevation — may have formed these valleys. The area is also marked by irregularly shaped, flat-floored depressions that can reach more than 80 kilometers (50 miles) across and almost 3 kilometers (2 miles) deep. The great widths and depths of these depressions suggest that they may have formed when the surface collapsed, rather than through the sublimation of ice into the atmosphere.

The enhanced color image was obtained by New Horizons’ Multispectral Visible Imaging Camera (MVIC). The image resolution is approximately 680 meters (2230 feet) per pixel. It was obtained at a range of approximately 33,900 kilometers (21,100 miles) from Pluto, about 45 minutes before New Horizons’ closest approach to Pluto on July 14, 2015.
Small Asteroid is Earth’s Constant Companion

A small asteroid has been discovered in an orbit around the Sun. Designated as 2016 HO3, the asteroid is a constant companion of Earth, and is likely to remain so for centuries to come. As it orbits the Sun, this new asteroid appears to circle Earth as well. It is too distant to be considered a true satellite of our planet, but it is the best and most stable example to date of a near-Earth companion, or “quasi-satellite.”

“Since 2016 HO3 loops around our planet, but never ventures very far away as we both go around the Sun, we refer to it as a quasi-satellite of Earth,” said Paul Chodas, manager of NASA’s Center for Near-Earth Object (NEO) Studies at the Jet Propulsion Laboratory. “One other asteroid — 2003 YN107 — followed a similar orbital pattern for a while over 10 years ago, but it has since departed our vicinity. This new asteroid is much more locked onto us. Our calculations indicate 2016 HO3 has been a stable quasi-satellite of Earth for almost a century, and it will continue to follow this pattern as Earth’s companion for centuries to come.”

In its yearly trek around the Sun, asteroid 2016 HO3 spends about half of the time closer to the Sun than Earth and passes ahead of our planet, and about half of the time farther away, causing it to fall behind. Its orbit is also tilted a little, causing it to bob up and then down once each year through Earth’s orbital plane. In effect, this small asteroid is caught in a game of leap frog with Earth that will last for hundreds of years.

The asteroid’s orbit also undergoes a slow, back-and-forth twist over multiple decades. “The asteroid’s loops around Earth drift a little ahead or behind from year to year, but when they drift too far forward or backward, Earth’s gravity is just strong enough to reverse the drift and hold onto the asteroid so that it never wanders farther away than about 100 times the distance of the Moon,” said Chodas. “The same effect also prevents the asteroid from approaching much closer than about 38 times the distance of the Moon. In effect, this small asteroid is caught in a little dance with Earth.”

Asteroid 2016 HO3 was first spotted on April 27, 2016, by the Pan-STARRS 1 asteroid survey telescope on Haleakala, Hawaii. The size of this object has not yet been firmly established, but it is likely larger than 40 meters (120 feet) and smaller than 100 meters (300 feet).

The Center for NEO Studies website has a complete list of recent and upcoming close approaches, as well as all other data on the orbits of known NEOs, so scientists and members of the media and public can track information on known objects. For more information, visit http://neo.jpl.nasa.gov/.
NASA’s Next Mars Rover Progresses Toward 2020 Launch

After an extensive review process and passing a major development milestone, NASA is ready to proceed with final design and construction of its next Mars rover, currently targeted to launch in the summer of 2020 and arrive on the Red Planet in February 2021. The Mars 2020 rover will investigate a region of Mars where the ancient environment may have been favorable for microbial life, probing the martian rocks for evidence of past life. Throughout its investigation, it will collect samples of soil and rock and cache them on the surface for potential return to Earth by a future mission.

“The Mars 2020 rover is the first step in a potential multi-mission campaign to return carefully selected and sealed samples of martian rocks and soil to Earth,” said Geoffrey Yoder, acting associate administrator of NASA’s Science Mission Directorate in Washington, DC. “This mission marks a significant milestone in NASA’s Journey to Mars — to determine whether life has ever existed on Mars, and to advance our goal of sending humans to the Red Planet.”

To reduce risk and provide cost savings, the 2020 rover will look much like its six-wheeled, one-ton predecessor, Curiosity, but with an array of new science instruments and enhancements to explore Mars as never before. For example, the rover will conduct the first investigation into the usability and availability of martian resources, including oxygen, in preparation for human missions.

Mars 2020 will carry an entirely new subsystem to collect and prepare martian rocks and soil samples that includes a coring drill on its arm and a rack of sample tubes. About 30 of these sample tubes will be deposited at select locations for return on a potential future sample-retrieval mission. In laboratories on Earth, specimens from Mars could be analyzed for evidence of past life on Mars and possible health hazards for future human missions.

Two science instruments mounted on the rover’s robotic arm will be used to search for signs of past life and determine where to collect samples by analyzing the chemical, mineral, physical, and organic characteristics of martian rocks. On the rover’s mast, two science instruments will provide high-resolution imaging and three types of spectroscopy for characterizing rocks and soil from a distance, also helping to determine which rock targets to explore up close. A suite of sensors on the mast and deck will monitor weather conditions and the dust environment, and a ground-penetrating radar will assess subsurface geologic structure.

The Mars 2020 rover will use the same sky crane landing system as Curiosity, but enhancements will give it the ability to land in more challenging terrain, making more rugged sites eligible as safe landing
candidates. “By adding what’s known as range trigger, we can specify where we want the parachute to open, not just at what velocity we want it to open,” said Allen Chen, Mars 2020 entry, descent, and landing lead at NASA’s Jet Propulsion Laboratory (JPL). “That shrinks our landing area by nearly half.”

Terrain-relative navigation on the new rover will use onboard analysis of downward-looking images taken during descent, matching them to a map that indicates zones designated unsafe for landing. “As it is descending, the spacecraft can tell whether it is headed for one of the unsafe zones and divert to safe ground nearby,” said Chen. “With this capability, we can now consider landing areas with unsafe zones that previously would have disqualified the whole area. Also, we can land closer to a specific science destination, for less driving after landing.”

There will be a suite of cameras and a microphone that will capture the never-before-seen or -heard imagery and sounds of the entry, descent, and landing sequence. Information from the descent cameras and microphone will provide valuable data to assist in planning future Mars landings, and make for thrilling video. “Nobody has ever seen what a parachute looks like as it is opening in the martian atmosphere,” said JPL’s David Gruel, assistant flight system manager for the Mars 2020 mission. “So this will provide valuable engineering information.”

Microphones have flown on previous missions to Mars, including NASA’s Phoenix Mars Lander in 2008, but never have actually been used on the surface of the Red Planet. “This will be a great opportunity for the public to hear the sounds of Mars for the first time, and it could also provide useful engineering information,” said Mars 2020 Deputy Project Manager Matt Wallace of JPL.

Once a mission receives preliminary approval, it must go through four rigorous technical and programmatic reviews — known as Key Decision Points (KDP) — to proceed through the phases of development prior to launch. Phase A involves concept and requirements definition; Phase B is preliminary design and technology development; Phase C is final design and fabrication; and Phase D is system assembly, testing, and launch. Mars 2020 has just passed its KDP-C milestone.

“Since Mars 2020 is leveraging the design and some spare hardware from Curiosity, a significant amount of the mission’s heritage components have already been built during Phases A and B,” said George Tahu, Mars 2020 program executive at NASA Headquarters. “With the KDP to enter Phase C completed, the project is proceeding with final design and construction of the new systems, as well as the rest of the heritage elements for the mission.”

The Mars 2020 mission is part of NASA’s Mars Exploration Program. Driven by scientific discovery, the program currently includes two active rovers and three NASA spacecraft orbiting Mars. NASA also plans to launch a stationary Mars lander in 2018, InSight, to study the deep interior of Mars. For more information, visit http://mars.nasa.gov/mars2020.
NASA Mars Orbiters Reveal Seasonal Dust Storm Pattern

After decades of research to discern seasonal patterns in martian dust storms from images showing the dust, the clearest pattern appears to be captured by measuring the temperature of the Red Planet’s atmosphere. For six recent martian years, temperature records from NASA Mars orbiters reveal a pattern of three types of large regional dust storms occurring in sequence at about the same times each year during the southern hemisphere spring and summer. Each martian year lasts about two Earth years.

“When we look at the temperature structure instead of the visible dust, we finally see some regularity in the large dust storms,” said David Kass of NASA’s Jet Propulsion Laboratory (JPL). He is the instrument scientist for the Mars Climate Sounder on NASA’s Mars Reconnaissance Orbiter and lead author of a report about these findings published in June by the journal Geophysical Research Letters. “Recognizing a pattern in the occurrence of regional dust storms is a step toward understanding the fundamental atmospheric properties controlling them,” Kass said. “We still have much to learn, but this gives us a valuable opening.”

Dust lofted by martian winds links directly to atmospheric temperature: The dust absorbs sunlight, so the Sun heats dusty air more than clear air. In some cases, this can be dramatic, with a difference of more than 35°C (63°F) between dusty air and clear air. This heating also affects the global wind distribution, which can produce downward motion that warms the air outside the dust-heated regions. Thus, temperature observations capture both direct and indirect effects of the dust storms on the atmosphere.

Improving the ability to predict large-scale, potentially hazardous dust storms on Mars would have safety benefits for planning robotic and human missions to the planet’s surface. Also, by recognizing patterns and categories of dust storms, researchers make progress toward understanding how seasonal local events affect global weather in a typical Mars year.

NASA has been operating orbiters at Mars continuously since 1997. The Mars Climate Sounder on Mars Reconnaissance Orbiter, which reached Mars in 2006, and the Thermal Emission Spectrometer on Mars Global Surveyor, which studied Mars from 1997 to 2006, have used infrared observations to assess atmospheric temperature. Kass and co-authors analyzed temperature data representative of a broad layer centered about 25 kilometers (16 miles) above the martian surface. That’s high enough to be more affected by regional storms than by local storms.

Most martian dust storms are localized, smaller than about 2000 kilometers (about 1200 miles) across and dissipating within a few days. Some become regional, affecting up to a third of the planet and persisting
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up to three weeks. A few encircle Mars, covering the southern hemisphere but not the whole planet. Twice since 1997, global dust storms have fully enshrouded Mars. The behavior of large regional dust storms in martian years that include global dust storms is currently unclear, and years with a global storm were not included in the new analysis. Three large regional storms, dubbed types A, B and C, all appeared in each of the six martian years investigated.

Multiple small storms form sequentially near Mars’ north pole in the northern autumn, similar to Earth’s cold-season arctic storms that swing one after another across North America. “On Mars, some of these break off and head farther south along favored tracks,” Kass said. “If they cross into the southern hemisphere, where it is mid-spring, they get warmer and can explode into the much larger Type A dust storms.”

Southern hemisphere spring and summer on modern-day Mars are much warmer than northern spring and summer because the eccentricity of Mars’ orbit puts the planet closest to the Sun near the end of southern spring. Southern spring and summer have long been recognized as the dustiest part of the martian year and the season of global dust storms, even though the more detailed pattern documented in the new report had not been previously described.

When a Type A storm from the north moves into southern-hemisphere spring, the sunlight on the dust warms the atmosphere. That energy boosts the speed of winds. The stronger winds lift more dust, further expanding the area and vertical reach of the storm. In contrast, the Type B storm starts close to the south pole shortly before the beginning of southern summer. Its origin may be from winds generated at the edge of the retreating south-polar carbon dioxide ice cap. Multiple storms may contribute to a regional haze.

The Type C storm starts after the B storm ends. It originates in the north during northern winter (southern summer) and moves to the southern hemisphere like the Type A storm. From one year to another, the C storm varies more in strength, in terms of peak temperature and duration, than the A and B storms do. For more information, visit http://mars.jpl.nasa.gov.

NASA Mars Rover Can Choose Laser Targets On Its Own

NASA’s Mars rover Curiosity is now selecting rock targets for its laser spectrometer — the first time autonomous target selection is available for an instrument of this kind on any robotic planetary mission. Using software developed at NASA’s Jet Propulsion Laboratory (JPL), Curiosity is now frequently choosing multiple targets per week for a laser and a telescopic camera that are parts of the rover’s Chemistry and Camera (ChemCam) instrument. Most ChemCam targets are still selected by scientists discussing rocks or soil seen in images the rover has sent to Earth, but the autonomous targeting adds a new capability.

During Curiosity’s nearly four years on Mars, ChemCam has inspected multiple points on more than 1400 targets by detecting the color spectrum of plasmas generated when laser pulses zap a target — more than 350,000 total laser shots at about 10,000 points in all. ChemCam’s spectrometers record the wavelengths seen through a telescope while the laser is firing. This information enables scientists to identify the
chemical compositions of the targets. Through the same telescope, the instrument takes images that are of the highest resolution available from the rover’s mast.

Autonomous Exploration for Gathering Increased Science (AEGIS) software had previously been used on NASA’s Mars Exploration Rover Opportunity, although less frequently and for a different type of instrument. That rover uses the software to analyze images from a wide-angle camera as the basis for autonomously selecting rocks to photograph with a narrower-angle camera. Development work on AEGIS won a NASA Software of the Year Award in 2011. “This autonomy is particularly useful at times when getting the science team in the loop is difficult or impossible — in the middle of a long drive, perhaps, or when the schedules of Earth, Mars, and spacecraft activities lead to delays in sharing information between the planets,” said robotics engineer Tara Estlin, the leader of AEGIS development at JPL.

The most frequent application of AEGIS uses onboard computer analysis of images from Curiosity’s stereo Navigation Camera (Navcam), which are taken routinely at each location where the rover ends a drive. AEGIS selects a target and directs ChemCam pointing, typically before the Navcam images are transmitted to Earth. This gives the team an extra jump in assessing the rover’s latest surroundings and planning operations for upcoming days.

To select a target autonomously, the software’s analysis of images uses adjustable criteria specified by scientists, such as identifying rocks based on their size or brightness. The criteria can be changed depending on the rover’s surroundings and the scientific goals of the measurements.
Another AEGIS mode starts with images from ChemCam’s own Remote Micro-Imager, rather than the Navcam, and uses image analysis to hone pointing of the laser at fine-scale targets chosen in advance by scientists. For example, scientists might select a threadlike vein or a small concretion in a rock, based on images received on Earth. AEGIS then controls the laser sharpshooting. “Due to their small size and other pointing challenges, hitting these targets accurately with the laser has often required the rover to stay in place while ground operators fine tune pointing parameters,” Estlin said. “AEGIS enables these targets to be hit on the first try by automatically identifying them and calculating a pointing that will center a ChemCam measurement on the target.”

From the top of Curiosity’s mast, the instrument can analyze the composition of a rock or soil target from up to about 7 meters (23 feet) away.

“AEGIS brings an extra opportunity to use ChemCam, to do more, when the interaction with scientists is limited,” said ChemCam Science Operation Lead Olivier Gasnault, at the Research Institute in Astrophysics and Planetology (IRAP), of France’s National Center for Scientific Research (CNRS) and the University of Toulouse, France. “It does not replace an existing mode, but complements it.”

The Curiosity mission is using ChemCam and other instruments on the rover as the vehicle investigates geological layers on lower Mount Sharp. The rover’s extended mission is analyzing evidence about how the environment in this part of Mars changed billions of years ago from conditions well suited to microbial life — if life ever existed on Mars — to dry, inhospitable conditions. For more information, visit http://mars.jpl.nasa.gov/msl.

Mars Gullies Likely Not Formed By Liquid Water

New findings using data from NASA’s Mars Reconnaissance Orbiter show that gullies on modern Mars are likely not being formed by flowing liquid water. This new evidence will allow researchers to further narrow theories about how martian gullies form, and reveal more details about Mars’ recent geologic processes. Scientists use the term “gully” for features on Mars that share three characteristics in their shape: an alcove at the top, a channel, and an apron of deposited material at the bottom. Gullies are distinct from another type of feature on martian slopes, streaks called “recurring slope lineae” (RSL), which are distinguished by seasonal darkening and fading, rather than characteristics of how the ground is shaped. Water in the form of hydrated salt has been identified at RSL sites. The new study focuses on gullies and their formation process by adding composition information to previously acquired imaging.

Researchers from the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland, examined high-resolution compositional data from more than 100 gully sites throughout Mars. These data, collected by the orbiter’s Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), were then correlated with images from the same spacecraft’s High Resolution Imaging Science Experiment (HiRISE) camera and Context Camera (CTX).

The findings showed no mineralogical evidence for abundant liquid water or its byproducts, thus pointing to mechanisms other than the flow of water — such as the freeze and thaw of carbon dioxide frost — as
being the major drivers of recent gully evolution. The findings were published in *Geophysical Research Letters*.

Gullies are a widespread and common feature on the martian surface, mostly occurring between 30° and 50° latitude in both the northern and southern hemispheres, generally on slopes that face toward the poles. On Earth, similar gullies are formed by flowing liquid water; however, under current conditions, liquid water is transient on the surface of Mars, and may occur only as small amounts of brine even at RSL streaks. The lack of sufficient water to carve gullies has resulted in a variety of theories for the gullies’ creation, including different mechanisms involving evaporation of water and carbon dioxide frost.

“The HiRISE team and others had shown there was seasonal activity in gullies — primarily in the southern hemisphere — over the past couple of years, and carbon dioxide frost is the main mechanism they suspected of causing it. However, other researchers favored liquid water as the main mechanism,” said Jorge Núñez of Johns Hopkin’s Applied Physics Laboratory (APL), the lead author of the paper. “What HiRISE and other imagers were not able to determine on their own was the composition of the material in gullies because they are optical cameras. To bring another important piece in to help solve the puzzle, we used CRISM, an imaging spectrometer, to look at what kinds of minerals were present in the gullies and see if they could shed light on the main mechanism responsible.”

Núñez and his colleagues took advantage of a new CRISM data product called Map-projected Targeted Reduced Data Records. It allowed them to more easily perform their analyses and then correlate the findings with HiRISE imagery.

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“On Earth and on Mars, we know that the presence of phyllosilicates — clays — or other hydrated minerals indicates formation in liquid water,” Núñez said. “In our study, we found no evidence for clays or other hydrated minerals in most of the gullies we studied, and when we did see them, they were erosional debris from ancient rocks, exposed and transported downslope, rather than altered in more...
recent flowing water. These gullies are carving into the terrain and exposing clays that likely formed billions of years ago when liquid water was more stable on the martian surface.”

Other researchers have created computer models that show how sublimation of seasonal carbon dioxide frost can create gullies similar to those observed on Mars, and how their shape can mimic the types of gullies that liquid water would create. The new study adds support to those models.

And while seasonal dark streaks on Mars have become one of the hottest topics in interplanetary research, they don’t hold much water, according to the latest findings from another NASA spacecraft orbiting Mars. The new results from NASA’s Mars Odyssey mission rely on ground temperature, measured by infrared imaging using the spacecraft’s Thermal Emission Imaging System (THEMIS). They do not contradict last year’s identification of hydrated salt at these flows, which since their 2011 discovery have been regarded as possible markers for the presence of liquid water on modern Mars. However, the temperature measurements now identify an upper limit on how much water is present at these darkened streaks: about as much as in the driest desert sands on Earth.

When water is present in the spaces between particles of soil or grains of sand, it affects how quickly a patch of ground heats up during the day and cools off at night. “We used a very sensitive technique to quantify the amount of water associated with these features,” said Christopher Edwards of Northern Arizona University in Flagstaff. “The results are consistent with no moisture at all and set an upper limit at three percent water.”

The features, RSL, have been identified at dozens of sites on Mars. A darkening of the ground extends downhill in fingerlike flows during spring or summer, fades away in fall and winter, then repeats the pattern in another year at the same location. The process that causes the streaks to appear is still a puzzle. “Some type of water-related activity at the uphill end still might be a factor in triggering RSL, but the darkness of the ground is not associated with large amounts of water, either liquid or frozen,” Edwards said. “Totally dry mechanisms for explaining RSL should not be ruled out.”

Edwards and Sylvain Piqueux of NASA’s Jet Propulsion Laboratory (JPL) analyzed several years of THEMIS infrared observations of a crater-wall region within the large Valles Marineris canyon system on Mars. Numerous RSL features sit close together in some parts of the study region. Edwards and Piqueux compared nighttime temperatures of patches of ground averaging about 44% RSL features, in the area, to temperatures of nearby slopes with no RSL. They found no detectable difference, even during seasons when RSL were actively growing. The report of these findings by Edwards and Piqueux is available online in the journal Geophysical Research Letters.

There is some margin of error in assessing ground temperatures with the multiple THEMIS observations used in this study, enough to leave the possibility that the RSL sites differed undetectably from non-RSL sites by as much as 1°C (1.8°F). The researchers used that largest possible difference to calculate the maximum possible amount of water — either liquid or frozen — in the surface material.
How deeply moisture reaches beneath the surface, as well as the amount of water present right at the surface, affects how quickly the surface loses heat. The new study calculates that if RSL have only a wafer-thin layer of water-containing soil, that layer contains no more than about 30 grams of water per kilogram of soil (1 ounce of water per 2 pounds of soil). That is about the same concentration of water as in the surface material of the Atacama Desert and Antarctic Dry Valleys, the driest places on Earth. If the water-containing layer at RSL is thicker, the amount of water per kilogram or pound of soil would need to be even less, to stay consistent with the temperature measurements.

Research published last year identified hydrated salts in the surface composition of RSL sites, with an increase during the season when streaks are active. Hydrated salts hold water molecules affecting the crystalline structure of the salt. “Our findings are consistent with the presence of hydrated salts because you can have hydrated salt without having enough for the water to start filling pore spaces between particles,” Edwards said. “Salts can become hydrated by pulling water vapor from the atmosphere, with no need for an underground source of the water.”

“Through additional data and studies, we are learning more about these puzzling seasonal features — narrowing the range of possible explanations,” said Michael Meyer. “It just shows us that we still have much to learn about Mars and its potential as a habitat for life.”

**NASA Rover Findings Point to a More Earth-Like Martian Past**

Chemicals found in martian rocks by NASA’s Curiosity Mars rover suggest the Red Planet once had more oxygen in its atmosphere than it does now. Researchers found high levels of manganese oxides by using a laser-firing instrument on the rover. This hint of more oxygen in Mars’ early atmosphere adds to other Curiosity findings — such as evidence about ancient lakes — revealing how Earth-like our neighboring planet once was.

This research also adds important context to other clues about atmospheric oxygen in Mars’ past. The manganese oxides were found in mineral veins within a geological setting the Curiosity mission has placed in a timeline of ancient environmental conditions. From that context, the higher oxygen level can be linked to a time when groundwater was present in the rover’s Gale Crater study area. “The only ways on Earth
that we know how to make these manganese materials involve atmospheric oxygen or microbes,” said Nina Lanza, a planetary scientist at Los Alamos National Laboratory in New Mexico. “Now we’re seeing manganese oxides on Mars, and we’re wondering, how the heck these could have formed?”

Microbes seem far-fetched at this point, but the other alternative — that the martian atmosphere contained more oxygen in the past than it does now — seems possible, Lanza said. “These high manganese materials can’t form without lots of liquid water and strongly oxidizing conditions. Here on Earth, we had lots of water but no widespread deposits of manganese oxides until after the oxygen levels in our atmosphere rose.”

Lanza is the lead author of a new report about the martian manganese oxides published in *Geophysical Research Letters*. She uses Curiosity’s Chemistry and Camera (ChemCam) instrument, which fires laser pulses from atop the rover’s mast and observes the spectrum of resulting flashes of plasma to assess targets’ chemical makeup.

In Earth’s geological record, the appearance of high concentrations of manganese oxide minerals is an important marker of a major shift in our atmosphere’s composition, from relatively low oxygen abundances to the oxygen-rich atmosphere we see today. The presence of the same types of materials on Mars suggests that oxygen levels rose there, too, before declining to their present values. If that’s the case, how was that oxygen-rich environment formed?

“One potential way that oxygen could have gotten into the martian atmosphere is from the breakdown of water when Mars was losing its magnetic field,” said Lanza. “It’s thought that at this time in Mars’ history, water was much more abundant.” Yet without a protective magnetic field to shield the surface, ionizing radiation started splitting water molecules into hydrogen and oxygen. Because of Mars’ relatively low gravity, the planet wasn’t able to hold onto the very light hydrogen atoms, but the heavier oxygen atoms remained behind. Much of this oxygen went into rocks, leading to the rusty red dust that covers the surface today. While Mars’ famous red iron oxides require only a mildly oxidizing environment to form, manganese oxides require a strongly oxidizing environment, more so than previously known for Mars.

Lanza added, “It’s hard to confirm whether this scenario for martian atmospheric oxygen actually occurred, but it’s important to note that this idea represents a departure in our understanding for how planetary atmospheres might become oxygenated.” Abundant atmospheric oxygen has been treated as a so-called biosignature, or a sign of extant life, but this process does not require life.

Curiosity has been investigating sites in Gale Crater since 2012. The high-manganese materials it found are in mineral-filled cracks in sandstones in the “Kimberley” region of the crater. But that’s not the only place on Mars where high-manganese abundances have been found. NASA’s Opportunity rover, exploring Mars since 2004, also recently discovered high manganese deposits thousands of miles from Curiosity. This supports the idea that the conditions needed to form these materials were present well beyond Gale Crater.
Annual Meeting of the Lunar Exploration Analysis Group (LEAG)

October 20–22, 2015
Columbia, Maryland

The annual meeting of the Lunar Exploration Analysis Group (LEAG) saw 118 people gather for 2.5 days at USRA Headquarters in Columbia, Maryland, to hear updates about LEAG activities, from NASA, and current lunar missions. The focus of the meeting was on lunar resources, prospecting, and *in situ* resource utilization. This included sessions on lunar volatiles and advanced concepts. For the first time, the meeting was streamed live over the Internet, which was a success.

During the meeting, the inaugural summit of the LEAG Curatorial Advisory Board (CAB) was held, which involved in-depth discussions regarding how LEAG could become more involved with the commercial sector and solicit more commercial participation in future LEAG meetings. At the end of the meeting, the final session was centered on producing findings that could be sent to the Science Mission and the Human Exploration and Operations Directorates of NASA. Ten findings were forwarded after discussion with the meeting regarding Lunar Reconnaissance Orbiter and Resource Prospector missions, polar volatiles, *in situ* resource utilization, lunar simulants, development of a Lunar Capabilities Roadmap, Public-Private partnerships, and regulatory risk.

The findings are posted on the LEAG website at [http://www.hou.usra.edu/meetings/leag2015/Meeting-Findings.pdf](http://www.hou.usra.edu/meetings/leag2015/Meeting-Findings.pdf). The meeting program and many of the presentations are available at [http://www.hou.usra.edu/meetings/leag2015/presentations/](http://www.hou.usra.edu/meetings/leag2015/presentations/).

The 2016 LEAG meeting will also be held at USRA Headquarters on November 1–3.
New Views of the Moon 2
May 24–26, 2016
Houston, Texas

On May 24–26 more than 120 lunar scientists from around the world attended the inaugural New Views of the Moon 2 (NVM-2) workshop at the Lunar and Planetary Institute (LPI) in Houston, Texas. This was the launch of an international initiative, led by the LPI and the Lunar Exploration Analysis Group (LEAG), to summarize discoveries from lunar missions and research that have occurred during the twenty-first century, and is a follow up to the New Views of the Moon book (NVM) published in 2006 (see http://minmag.geoscienceworld.org/content/70/6/747).

Much has changed since NVM, which only covered up to the beginning of the twenty-first century. The workshop was centered around themes and advances that have arisen with new data/missions. For example, NVM did not discuss the issue of lunar volatiles in any depth; since its publication we now know much more about volatiles in the lunar interior as well as on the surface. Invited presentations from chapter leads set the framework for discussion about what should be in each chapter and began to resolve areas that overlapped between chapters. The workshop also discussed proposals for new chapters that were submitted to the steering committee — Lisa Gaddis, Brad Jolliff, Sam Lawrence, Steve Mackwell, Clive Neal, and Chip Shearer — for evaluation.

Unlike NVM, NVM-2 will be comprised of more but shorter chapters with an introductory chapter summarizing the missions to the Moon that have occurred since 2000 and up to the time of publication (around 2019). Chapter writing teams are currently being put together, and even if people were not at the workshop, they can contact the chapter leads to volunteer their services. Students and early career lunar scientists and engineers are particularly encouraged to get involved because they will be writing NVM-3! Details of the chapters and chapter leads can be found at http://www3.nd.edu/~cneal/NVM-2/.

Workshops are planned in 2017 and 2018, including meetings outside the United States. In 2017, the NVM-2-Europe workshop will be held during May 2017 in conjunction with the European Lunar Symposium in Münster, Germany (http://sservi.nasa.gov/event/european-lunar-symposium-2017/). In 2018, the NVM-2-Asia will be held in Japan. Please follow the LPI and LEAG websites (http://www.lpi.usra.edu/leag/) for details, which will be posted as they become available.
Meeting Highlights continued . . .

Enceladus and the Icy Moons of Saturn
July 26–29, 2016
Boulder, Colorado

The planetary science community gathered in Boulder, Colorado, the week of July 26–29, 2016, to attend the conference on Enceladus and the Icy Moons of Saturn.

This 3.5-day meeting featured 87 abstracts representing 9 countries. Although the main focus was on the stunning discoveries of the Cassini orbiter, groundbased and theoretic studies were also presented and discussed. The program allowed time for focused discussion after each session, and covered a wide range of topics from constraints on the interior of Enceladus and the chemistry of its subsurface ocean to speculations regarding the unproven possibility that the ring and satellite system at Saturn might be rather young. A highlight of the meeting on the last day was a formatted debate regarding the exobiological potential of Enceladus and its subsurface ocean.

A total of 104 people participated in the conference, which will be followed by a dedicated book summarizing the current state of knowledge on Saturn’s icy moons, to be published as part of the Space Science Series published by the University of Arizona Press in collaboration with the Lunar and Planetary Institute.

The program and abstracts for the conference are available on the meeting website at http://www.hou.usra.edu/meetings/enceladus2016/.
“Spotlight on Education” highlights events and programs that provide opportunities for planetary scientists to become involved in education and public engagement. If you know of space science educational programs or events that should be included, please contact the Lunar and Planetary Institute’s Education Department at education@lpi.usra.edu.

Upcoming Public Event Opportunities

Upcoming opportunities exist for educator and public engagement around the broader topics of NASA planetary exploration.

- NASA’s Solar System Ambassadors (http://solarsystem.nasa.gov/ssa/directory.cfm) can volunteer to assist with your events.
- To find out about existing events with which you can assist, check out the NASA Museum Alliance events at http://informal.jpl.nasa.gov/museum/Visit.

International Observe the Moon Night

October 8, 2016, will mark the next International Observe the Moon Night (InOMN), an annual worldwide public event that encourages observation, appreciation, and understanding of our Moon and its connection to NASA planetary science and exploration. Everyone on Earth is invited to join the celebration by hosting or attending an InOMN event and uniting on one day each year to look at and learn about the Moon together. For more information, visit http://observethemoonnight.org/.

Total Eclipse of the Sun

On August 21, 2017, there will be a total eclipse of the Sun visible from the United States. The path of the total eclipse is only about 97 kilometers (60 miles) wide and goes from a beach in Oregon to a beach in South Carolina. The National Science Teachers Association (NSTA) is making available a popular-level introduction to help explain the eclipse and how to view it to students and the public: http://www.nsta.org/publications/press/extras/files/solarscience/SolarScienceInsert.pdf. For more information, visit http://sunearthday.nasa.gov/discoveries/science/2017-eclipse.php.
DPS Early Career Presenters Review

All early career scientists preparing to present research at the Division of Planetary Science (DPS) conference this fall are invited to attend this educational opportunity to receive feedback from seasoned presenters! Participants in the Early Career Presenters Review have the opportunity to present their DPS 48/EPSC 11 oral or poster presentation and receive feedback before presenting during the regular meeting. In addition to presenting their research, participants have the opportunity to network with their peers and future colleagues. To participate, please register at https://www.surveymonkey.com/r/dps2016_early_career. The deadline to register is 5:00 p.m. U.S. Central Daylight Time, October 12, 2016. Registration is limited to 20 presenters.

Scientists wishing to participate by providing feedback to the early career presenters should contact Andy Shaner at shaner@lpi.usra.edu.

LPI Summer Intern Program

The Lunar and Planetary Institute invites undergraduates with at least 50 semester hours of credit to experience cutting-edge research in the lunar and planetary sciences. As a Summer Intern, you will work one-on-one with a scientist at the LPI or at the NASA Johnson Space Center on a research project of current interest in lunar and planetary science. The application deadline for the 2017 program will be Friday, January 6, 2017. Additional information and the application form will be available starting October 7 at the LPI intern website, http://www.lpi.usra.edu/lpiintern/.

CosmoQuest Surveys

CosmoQuest's goal is to create a community of people wanting to work together to understand the universe; a community of people doing science and who can explain why what they do matters. They would like advice and suggestions from scientists, student, educators, and others, and have designed surveys to gather your input. To participate, visit http://cosmoquest.org/x/blog/2016/08/help-us-improve-cosmoquest/. 

Spotlight on Education continued . . .
Spotlight on Education continued...

The Universe in the Classroom

A new edition of The Universe in the Classroom is now available on the Astronomical Society of the Pacific website. “Recent Lunar Science Discoveries and an Opportunity to Celebrate Them” describes how you can get involved in International Observe the Moon Night, and how recent NASA missions have changed the way we view our nearest celestial neighbor. Past articles are also available. For more information, visit https://www.astrosociety.org/publications/universe-in-the-classroom/.

NASA’s “Science WOW!” Newsletter

NASA has a new science education newsletter. Science starts with a question, and so will “Science WOW!” Each week’s message will kick off with a science question and a link to where you can find the answer. “Science WOW!” will also highlight an awesome science education tool each week. Visit https://www.nasa.gov/education/sciencewow/.
In Memoriam

Patti Grace Smith, 1947–2016

Patti Grace Smith, a federal aviation official who loosened the regulatory reins in Washington to help spur the growth of the embryonic commercial space transportation industry, died on June 5 in Washington after suffering from pancreatic cancer. She was 68.

In September 1963, twelve African American teenagers dared to integrate the Tuskegee High School in Macon County, Alabama. Defying Governor George Wallace’s proclamation of “segregation now, segregation tomorrow, and segregation forever” and the guns of the Alabama State Troopers surrounding the building, these kids, with the support of their brave families and U.S. Marshals, went to school. The teenagers became the plaintiffs in the landmark case Lee vs. Macon County Board of Education, which led to the blanket desegregation order upheld by the Supreme Court in 1967. One of those teenage plaintiffs was Patricia Jones, but most of us knew her as Patti Grace Smith.

Smith was the first-born child of parents who served as ground support at the Tuskegee Airfields during World War II, her father Douglas Jones Sr. in the Army Air Corp, and her mother Wilhelmina Jones as a civilian. Although not pilots, Smith’s parents are recognized by the U.S. Park Service as Tuskegee Airmen. Smith credited her father for instilling in her the unequivocal belief that she could become whatever she wanted to be. He taught her that there were no boundaries.

Smith went to college at Tuskegee Institute, where she graduated with honors with a degree in English, and then continued graduate studies at Auburn University, George Washington University, and Harvard University. She first worked in the broadcasting industry, but soon left to begin her 28-year career in government service. In the late 1970s through mid 1980s she worked at the Federal Communications Commission on satellite matters. From there she moved to the Defense Communications Agency, and then in 1994, started work at the Federal Aviation Administration (FAA).

In the meantime, a bipartisan space initiative was unfolding. When President Ronald Reagan was told that Deke Slayton, the Mercury Seven astronaut, and his company Space Services needed permission from 17 different agencies to launch the Conestoga, the first private rocket, he ordered that the process be coordinated through one agency. Elizabeth Dole, the Secretary of Transportation, seized the responsibility for the Department of Transportation. In the mid 1990s, Vice President Al Gore, as part of his effort to streamline government, took the next step and moved responsibility for commercial private space regulation into a new Office of Commercial Space Transportation at the FAA.

Already having worked at the FAA for a few years, in 1997 Smith was asked to lead the Office, with the title Associate Administrator for Commercial Space Transportation. Her job was to establish an effective and efficient regulatory regime for commercial private space industry. The odds of success were stacked...
against her. At the beginning of her tenure, there was no meaningful commercial space industry clamoring for FAA authorizations. Private sector proponents, her natural allies, were disregarded or ignored. Ideas were met with ridicule ("You want to license what? An inland spaceport?") or hostility ("There is only one space agency in town, and it ain’t the FAA"). The most difficult struggle, however, was within the FAA. The FAA template was based on rules and regulations created over 70 years regulating the airline industry. No one had experience developing regulations for a nascent industry. Airline safety standards and operational regulations were complex and stringent. The people who implemented them were rigid and intransient.

Smith had the extraordinary blend of skills, character, and personality to implement great change. She had great political sense, knowing the sources of power and when to exploit them. People instantly liked her and quickly grew to trust and respect her. She was masterful at building bipartisan alliances. She understood with great precision the regulations that would be acceptable to government and industry, and served as their bridge while her team crafted rules and regulations to nurture the new industry. Pick any historic commercial space milestone, whether it be SpaceShipOne, SpaceX, Mojave Spaceport, NASA’s Commercial Orbital Transportation Services (COTS), or any other meaningful private space endeavor. The rules and regulations crafted by Smith and her team are a fundamental pillar for these achievements. Her office’s regulatory regime provided stability and respect for the industry, without any undue burdens.

Although Smith left the FAA in 2008, she remained an active champion for the space industry. She was an in-demand consultant for many space companies, large and small. Serving on the NASA Advisory Council, including as Chairperson of the Commercial Space Committee, Smith watched over her former office, often serving as informal referee for NASA vs. FAA skirmishes. She served on the Board of Directors of the Space Foundation since 2010, and at the time of her death was in line to be Chairperson, which would have made her the first African American and first woman to hold that position.

— Text courtesy of Lon Levin, Director Emeritus and Former Chairman, Space Foundation
In Memoriam continued . . .

Andrei Valerieveich Ivanov, 1937–2016

On July 7, 2016, Andrei Valerieveich Ivanov passed away after a struggle with cancer. Ivanov was a friend and colleague, a distinguished scientist, Doctor of Geological and Mineralogical Sciences, member of the international Meteoritical Society, and a leading researcher at the Vernadsky Institute’s Laboratory of Meteoritics. He was key in the Soviet lunar sample analysis and curation.

Ivanov was born in the village of Marfino in Moscow Oblast into the family of an official. He graduated from the Department of Geochemistry of the Geology Faculty of Moscow State University (MGU) in 1960. From 1960 to 1962 he worked as an engineer in the Chita hydrogeology expedition. He joined the Laboratory of Isotope Geochemistry at the Vernadsky Institute of Geochemistry (GEOKHI) in 1962, and worked there for eight years, defending his Ph.D. in 1969. From 1969 to 1974, Ivanov worked at the USSR Institute for Space Research (IKI), then returned to the Vernadsky Institute in 1975 and remained there throughout his further career. He served as a member of the Committee On Meteorites (KMET) from 1979 to 2004.

Ivanov’s scientific career focused on investigations of extraterrestrial materials. His work on fine-grained (10+-micrometer) spherical deposits of probable extraterrestrial origin, found in peat deposits from the region of the Tunguska explosion, was widely known. Beginning in the late 1960s, he was a major participant in the receiving and study of the first lunar samples returned to Earth by the Soviet robotic Moon landers. He told wonderful stories of opening the sample-return capsules in the vacuum glove chamber, and seeing the lunar soil emerge before his eyes.

Ivanov’s lunar research focused on the effects of space environmental factors on the formation conditions of the lunar regolith. In 1971, this became the foundation of one of his major scientific reports, “Antioxidative properties of ultradispersed, simple materials on the surfaces of extraterrestrial bodies.”

Ivanov committed nearly 30 years to the study of the unique Kaidun meteorite. Through his investigations, he identified new types of meteorite material and discovered a series of new mineral phases, including the new mineral florenskyite, an unusual phosphide (FeTiP) found in Kaidun. Ivanov’s colleagues later identified an even rarer isomorph (FeCrP) and named it andreyivanovite in his honor. His studies were the first to find traces of fluid metasomatic changes in the components of Kaidun.

Ivanov was the author of more than 200 scientific publications and two books; in 1977, he was awarded the USSR’s Medal “For Labor Valor,” and the asteroid 5761 Andreivanov was named in his honor. In recent years, Ivanov worked on systematizing and cataloging the Vernadsky Institute’s collection of lunar samples. He saw this as his personal duty to future generations of lunar investigators.

Ivanov’s passing is an irreplaceable loss for the Laboratory of Meteoritics and the whole Vernadsky Institute. His personality naturally combined professionalism, broad interests, the highest ethics, and openness to people, and we could always count on his kind words, advice, and guidance.

— Text courtesy of friends and colleagues from Vernadsky Institute
Antonín Rükl, 1932–2016

Antonín Rükl, noted lunar cartographer, selenographer, prolific author, and retired director of the Prague Planetarium, passed away on July 12 at his home in Prague, Czech Republic.

Rükl was born in Čáslav, Czechoslovakia. As a student he developed what was to be a lifelong interest in astronomy. He graduated from the Czech Technical University in 1956, and then joined the staff of the astronomical department of the Institute of Geodesy in Prague. In 1960, he joined the Prague Planetarium, eventually becoming deputy director and then head. He also became chairman of the Planetary Section of the Czechoslovak Astronomical Society and served as vice president of the International Planetarium Directors Conference from 1996 until 1999. He retired at the end of 1999.

During his career he helped to popularize astronomy and authored many books on the subject. An expert in selenography — the science of mapping the Moon — he published several highly regarded books, including *Atlas of the Moon*. Among his other internationally known books are *A Guide to the Stars, Constellations, and Planets* and *Constellation Guidebook*. A minor planet (15395) was named after him in 2000.
USRA Names Louise M. Prockter Director of the Lunar and Planetary Institute

The Universities Space Research Association (USRA) has named Dr. Louise M. Prockter as Director of the Lunar and Planetary Institute (LPI) in Houston, Texas, effective September 6, 2016. Prockter is the first woman to serve as LPI Director.

Since 1969, USRA has managed the LPI — a premier research organization that serves NASA and the planetary science community and conducts planetary science research through a core of staff scientists, visiting researchers, and post-doctoral fellows. As Director, Prockter will assume the leadership and management of the LPI. She will work with NASA to develop a forward-looking vision for the Institute in its service to the community and in supporting NASA’s strategic goals in planetary science and solar system exploration.

“We are delighted to welcome Louise to USRA. Her technical expertise and proven track record in management make her the ideal candidate to lead LPI into the future,” says Dr. Jeffrey Isaacson, President and CEO of USRA. “Above all, she is committed to driving the Institute forward and extending its 47-year history of preeminent service to NASA and the lunar and planetary science community.”

Prockter has an internationally recognized record in planetary science research and has been a leader in NASA mission science development, operations, and management. Notable are her leadership roles at The Johns Hopkins University Applied Physics Laboratory (APL) Science Branch Space Sector and at the Planetary Exploration Group, where she was responsible for overseeing and developing a group of world-class planetary scientists, staffing space missions, budget and facilities management, and strategic planning. Her mission experience includes leadership roles on NASA’s Europa Multiple FlyBy flagship mission, and the MESSENGER Discovery Mission as well as team affiliate roles on the Near Earth Asteroid Rendezvous and the Galileo Extended Mission (GEM). Prockter has served on numerous panels for the National Academy of Sciences and NASA, including the Space Studies Board and the Planetary Decadal Survey for 2013–2022, “Vision and Voyages.”

“I am excited to have Louise join the USRA science leadership team,” says Dr. Nicholas White, Senior Vice President for Science at USRA. “Louise will bring a new perspective to lead the LPI through its next phase in supporting NASA’s mission to explore the solar system.”

“With Louise at the helm, I am confident that the Institute will attain the next level in service to NASA and the planetary community,” says Dr. Stephen Mackwell, outgoing LPI Director.

Prockter holds Ph.D. and M.S. degrees in Planetary Geology from Brown University. She received her undergraduate degree in Geophysics from Lancaster University, UK. Prockter is a Fellow of the Geological Society of America and has authored or co-authored numerous papers in a number of diverse fields of research.
She succeeds Mackwell, who was named as the USRA Corporate Director of Science Programs earlier this year. Mackwell has led the LPI since 2002, and has received numerous accolades for his service, including being honored by the International Astronomical Union as a “valued steward of the science community” with the naming of main-belt asteroid 5292 Mackwell.

**Alan Stern Receives Distinguished Public Service Medal**

The National Aeronautics and Space Administration has bestowed its highest honor, the NASA Distinguished Public Service Medal, to Dr. Alan Stern of the Southwest Research Institute. As principal investigator of the New Horizons mission, Stern led the team that returned remarkable imagery and other data from the Pluto system last summer, generating headlines worldwide and setting a record for the farthest world ever explored.

“Leading New Horizons has been the greatest honor of my lifetime, but it’s important to recognize so many others who also contributed to the success of this mission,” Stern commented on receiving the award. “I dedicate this award to the 2500 men and women who worked so hard to build, launch, and fly New Horizons across the solar system to explore Pluto and its system of moons.”

Stern and the New Horizons team have been honored multiple times since the flyby. Stern was recently named one of the TIME 100 most influential people in the world — his second such designation — and the American Astronomical Society (AAS) awarded him its Carl Sagan Memorial Award. Team achievements include the AAS Neil Armstrong Space Flight Achievement Award and the Aviation Week and Space Technology 2016 Laureate Award for space exploration. The NASA mission also was named...
among the top science news stories of 2015 by Discover Magazine and Science News. The New Horizons science team has won more than two dozen awards to date.

NASA’s Distinguished Public Service Medal is the highest form of recognition given to citizens whose distinguished service or vision has contributed to the advancement of NASA and the nation, demonstrating a level of excellence that has made an indelible impact to NASA mission success.

USRA Issues Statement About Leadership of SOFIA Science Mission Operations

From the office of Dr. Jeffrey A. Isaacson, USRA President and Chief Executive Officer:

“After 7 years of exemplary leadership, Dr. Erick Young will be stepping down as Director, SOFIA Science Mission Operations (SMO), in order to pursue full-time research. Since 2009, Erick has played a central role in transforming SOFIA from a developmental program to a fully operational airborne observatory. Among other things, he oversaw the commissioning and operation of eight flight instruments (along with two upgrades); brought SMO to full operational capability in February 2014; and established a sustainable planning and operating rhythm to enable routine SOFIA observations, including three deployments to the Southern Hemisphere.

Erick’s many contributions to USRA, NASA, and the astronomy and astrophysics communities will long be remembered.

I am pleased to announce that Dr. Harold Yorke will assume the role of Director, SOFIA Science Mission Operations, effective October 15, 2016. Hal comes to USRA from the Jet Propulsion Laboratory (JPL) in Pasadena, CA, and will bring extensive scientific and leadership experience to guide SOFIA over the coming years. Among his numerous management and research positions, Hal served as the NASA Project Scientist for the Herschel Space Observatory and the Science Division Manager at JPL. His research is recognized internationally, and includes numerical radiation-hydrodynamics simulations of astrophysical plasmas, especially as related to star and planet formation; the study of atoms, molecules, and dust in the interstellar medium (ISM); observations of the ISM and star forming regions at millimeter, infrared, optical, ultraviolet, and X-ray wavelengths; and design studies for space-based and suborbital far-infrared and sub-millimeter observatories.

Hal is no stranger to USRA, having served on USRA’s SOFIA Science Council.

Please join me in thanking Erick for his many contributions, and welcoming Hal to his new position at USRA.”
Fifty Years of Moon Dust: Surveyor 1 was a Pathfinder for Apollo

Before humans could take their first steps on the Moon, that mysterious and forbidding surface had to be reconnoitered by robots. When President John Kennedy set a goal of landing astronauts on the lunar surface in 1961, little was known of that world, beyond what could be gleaned from observations by telescopes. We knew it was rocky, bleak and heavily cratered — how might these conditions affect the landing of a spacecraft there? Was the surface sufficiently solid to support the 14,969-gram (33,500-pound) Apollo lunar lander? Or was it so deeply covered in dust from billions of years of meteorite impacts, as some theorized, that the lunar module would simply sink out of sight, dooming the astronauts? These and a hundred other questions about the surface composition dogged mission planners, so a robot would make the dangerous journey first — the lunar lander from NASA’s Jet Propulsion Laboratory (JPL).

The first probes to reach Earth’s nearest neighbor were Russian. Luna 2 impacted the surface in 1959, and the Moon was photographed from orbit by another Soviet robot later that year. The U.S. flew a series of impactor probes called Ranger; the first success of that program was Ranger 7, which returned 4300 images of increasing resolution during the final 17 minutes of flight in 1964. The USSR scored another coup when it made the first soft landing and took the first low-resolution photos of the Moon’s surface, in February 1966. A series of U.S. mapping spacecraft called Lunar Orbiter photographed the Moon from orbit in 1966 and 1967. But it would be the Surveyors that would scout that rugged surface for Apollo, and 50 years ago, the first of that series of landers touched down successfully. Surveyor 1 landed on the Moon on June 2, 1966.

The leap from impactors and airbag landings to a controlled landing was a big one, and required new, never-before-attempted techniques in guidance, navigation, robotics, and imaging. Surveyor was the first spacecraft of its kind, a go-for-broke program that was racing to return data even as the Apollo program was in high gear. The first crewed Apollo landings were expected sometime in 1968 or 1969, so time was short.

Justin Rennilson, formerly of JPL, was the co-principal investigator on the Surveyor television experiment. “Planning for Apollo required getting really high-resolution images showing the details of the lunar surface, because they were talking about designing a spacecraft that would safely land on the lunar surface as we would with Surveyor,” he said. “Telescopic photographs of
the Moon were taken from Earth, but what we needed were high-resolution images to study the rocks on the lunar surface. Even something two feet in size could topple a spacecraft.”

The Surveyor program was already in the pipeline before President Kennedy announced his goals for lunar exploration. Surveyor had been intended as a scientific investigation of the Moon. But its mission was revised immediately after the young president’s address to a joint session of Congress: “I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth.” With those words, NASA would steer the bulk of Surveyor’s mission toward supporting that goal.

The first Surveyors were tasked with reaching the lunar surface successfully via a soft landing, then investigating the physical properties of the nearby landscape to understand the risks and challenges to landing astronauts there. But that first successful landing was far from assured. NASA had accomplished flybys of Venus and Mars, but had not attempted landing on any celestial body before Surveyor. Among hundreds of other challenges, an uninterrupted communication link for navigation and control would be critical to success.

“We figured the probability of success at around 10 to 15 percent,” Rennilson said. “We had a lot of problems, not only on the spacecraft but also at JPL. The lab, which managed the Surveyor program for NASA, had just recently finished a new space flight operations facility, the SFOF. This had a telemetry connection with Goldstone, a tracking station in the California desert (now part of NASA’s Deep Space Network) that would be accommodating the communication needs of the spacecraft during landing. But there were signal dropouts. They didn’t know what to do, so they sent me to Goldstone.” He arrived at the tracking station just prior to the landing on June 2.

Surveyor had been sent on a direct trajectory — it would not enter lunar orbit before landing, but would hurtle directly toward the surface at 9700 kilometers per hour (6000 miles per hour). The thrusters had to fire at precisely the right moment and maintain perfect orientation to communicate with Earth, all the way down. “I remember sitting there watching the oscilloscope as the spacecraft was coming down, all the way to the lunar surface. ‘God, the signal is still there and it is still working!’ I thought. We were successful and it was just astounding.” Immediately upon Surveyor’s arrival on the Moon, Rennilson hopped another plane to return to JPL.

After the failure of a number of the Ranger spacecraft en route to the Moon, the success of the first Surveyor landing was an incredible relief. William Pickering, the director of JPL from 1954 through 1976, recalled in a 1978 Caltech interview that he had some concerns about the television networks’ request to carry the landing live on what he thought was to be national coverage: “We finally ended up by agreeing to let them do it, and we kept our fingers crossed and hoped it was going to be all right. But the thing that startled me was that about a half an hour before it was due to land, one of the network people said, ‘Oh, by the way, we’re live all over the world,’ which really sort of shook me. Fortunately, it worked, and in fact, sometime later a friend of mine told me that he was in Paris, and he just idly turned on the television set and there was Surveyor 1 landing on the Moon.”
With Surveyor 1 down and safe, the exploration of the Moon would now begin in earnest. The landing site was a few dozen miles north of a 21-kilometer-wide (13-mile-wide) crater called Flamsteed that resided within Oceanus Procellarum, the largest of the Moon’s smooth basaltic mare, or plains. The first views of the lunar surface were striking, but not easily acquired. Photography from space was still in its infancy.

The camera was advanced for its time, a slow-scan television imager with a zoom lens — the first time such an arrangement had been used in space. The goal of the researchers was to gather enough imagery to identify and investigate specific surface features, and also to create panoramic photos that would allow them to get a sense of the overall nature of the surface and any threats it might pose to the Apollo lunar lander.

The first sets of panoramic images were created using a then-new technique of taking instant-photography images from a small TV screen and then assembling the photographs into a larger image. Rennilson remembers the process vividly: “We had a Polaroid camera attached to a 5-inch-diameter CRT so that you could capture images on Polaroid film. These images were given to a crew that we had trained — who would put them down in a particular order — to create the panoramas.” That crew trained long and hard to prepare for the process. “We got so that after years of practicing, we were able to put down a panorama about three to four minutes after completing all that panning of the lunar surface.”

By the end of Surveyor 1’s mission six months after it landed on the Moon, 11,240 images had been returned, allowing for the creation of dozens of wide panoramas and allowing the examination of details as small as 1 millimeter (0.04 inches) in diameter. Images of the three footpads demonstrated that not only was landing on the Moon possible, but that the lander had not sunk into deep Moon dust — as was feared by some scientists — but had landed on a firm, supportive surface. Beginning with Surveyor 3, a scoop attached to an extendable arm allowed scientists to investigate the texture and hardness of the lunar surface. By the time Surveyor 7 completed operations on the Moon in February 1968 — just 10 months before Apollo 8 orbited the Moon — the pathway to the first crewed lunar landing of Apollo 11 on July 20, 1969, was open. The Surveyor program had been critical to that accomplishment.

Rennilson concludes: “The Chinese have an interesting saying: ‘When you take a drink of water, you should think of the source.’ I think that applies to the early unmanned space program. JPL has engineered so much of the modern stuff we do in space today. My remembrances are primarily about all the great things that we saw. So when Apollo landed, and when Curiosity landed on Mars, it was a great feeling.”
BOOKS

Encyclopedia of Planetary Landforms.
Edited by Henrik Hargitai and Ákos Kereszturi. Springer. 2015, 2460 pp. in three volumes, Hardcover, $1500.00. www.springer.com

This encyclopedia provides a snapshot of our current geological knowledge on solid-surface solar system bodies. Each entry contains information about the feature’s morphology, its interpretation, proposed formation models, distribution and occurrence, planetary or terrestrial analogs, and research history. The entries are fully referenced. All image captions include original image IDs. More than 600 named planetary feature types are discussed in the encyclopedia, covering a wide range of scales — from micrometers to global scale — and also includes landform types (structural or topographic features), parts of landforms, terrain types or surface textures, surface patterns, and features identified at wavelengths extending from visible to radio waves (e.g., albedo, thermal infrared, and radar features). The book covers features formed by impact, aeolian, magmatic, volcanic, tectonic, fluvial, lacustrine, marine and coastal, mass movement, sedimentary, desiccation, liquefaction, periglacial, glacial, nival, sublimation, collapse, weathering, and selective erosion, including complex processes. This reference work also includes original figures, line drawings, annotated photomosaics, and the latest spacecraft images, thematic, and distribution maps.

A History of the Solar System.

This well-illustrated book presents a compact history of the solar system from its dusty origins 4,600,000 years ago to the present day. Its primary aim is to show how the planets and their satellites, comets, meteors, interplanetary dust, solar radiation, and cosmic rays continually interact, sometimes violently, and it reflects humanity’s progress in exploring and interpreting this history. The book is intended for a general readership at a time when human and robotic exploration of space is often in the news and should also appeal to students at all levels. It covers the essentials but refers to a large literature that can be accessed via the Internet.


Since publication of the first edition of this book, there has been more than a decade of new readings and images taken by shuttles, rovers, and the Hubble Telescope. Each time they have passed by, orbited, and landed on the Moon, we have accumulated an incredible amount of data about our satellite and about
During this time, stargazing technology has advanced to an unprecedented level of sophistication. Even “basic” low-tech binoculars and telescopes permit astounding views of the night sky. This second edition of Moon Observer’s Guide has been updated and revised throughout to incorporate these exciting advances, including more than 20 new images and information about new digital imaging techniques and technology, such as digital single lens reflex (DSLR) cameras, webcams, and mobile apps. The updates also include the latest science garnered from lunar probes and missions recently and currently exploring the Moon. Topics covered include the birth of the Moon, the Moon’s orbit, guidelines for choosing binoculars and telescopes, ways of recording observations, digital and conventional photography, safety tips for observing, and eclipses and occultations. This book provides practical guidance to amateur astronomers viewing with the naked eye or with binoculars and telescopes. Included is a detailed 28-day Moon-watching guide, complete with maps, that describes lunar geology and the various causes of physical features, such as craters and volcanos. This is an ideal reference for beginning and experienced astronomers alike.

**Glaciovolcanism on Earth and Mars: Products, Processes and Palaeoenvironmental Significance.**

By John L. Smellie and Benjamin R. Edwards. Cambridge University Press, 2016, 490 pp., Hardcover, $140.00. [www.cambridge.org](http://www.cambridge.org)

The study of volcano-ice interactions, or “glaciovolcanism,” is a field experiencing exponential growth. This comprehensive volume presents a discussion of the distinctive processes and characteristics of glaciovolcanic eruptions, their products, and landforms, with reference to both terrestrial and Mars occurrences. Supported by abundant diagrams and photos from the authors’ extensive collections, this book outlines where eruptions have occurred and will occur in the future on Earth, the resulting hazards that are unique to volcano-ice interactions, and how the deposits are used to unravel planetary palaeoclimatic histories. It has a practical focus on lithofacies, glaciovolcanic edifice morphometry and construction, and applications to palaeoenvironmental studies. Providing the first global summary of past and current work, this book also identifies those areas in need of further research, making this an ideal reference for academic researchers and postgraduate students, in the fields of volcanology, glaciology, planetary science, and palaeoenvironmental studies.

**Space Physics: An Introduction.**


This textbook, derived from courses given by three leading researchers, provides advanced undergraduates and graduates with up-to-date coverage of space physics, from the Sun to the interstellar medium. Clear explanations of the underlying physical processes are presented alongside major new discoveries and knowledge gained from space missions, groundbased
observations, theory, and modeling to inspire students. Building from the basics to more complex ideas, the book contains enough material for a two-semester course but the authors also provide suggestions for how the material can be tailored to fit a single semester. End-of-chapter problems reinforce concepts and include computer-based exercises specially developed for this textbook package. Free access to the software is available via the book’s website and enables students to model the behavior of magnetospheric and solar plasma. This book has an extensive glossary recaps new terms and carefully selected further reading sections encourage students to explore advanced topics of interest.

**Geoscience Handbook 2016: AGI Data Sheets, Fifth Edition.**

For more than 40 years, American Geoscience Institute’s Data Sheets have been a critical tool for the geoscientist in the field, the lab, and the classroom. The book evolved into its current, full-color, and spiral-bound format with the 2005 debut of the fourth edition. Now AGI has tapped some of the best minds in the geosciences to produce this fifth edition. Featuring the contributions of over 240 experts worldwide in their respective fields, this new, expanded edition has more than 470 full-color pages. Three years of work went into the *Geoscience Handbook 2016* to broaden its scope across the disciplines. With more than 170 complete new data sheets, and full revisions of prior data sheets, over 85% of the content is either new or revised. The *Geoscience Handbook* is the quick reference tool for key metrics and concepts, a guide to cornerstone papers and recent developments, as well as short tutorials on topics that may not be familiar to all geoscientists.

**SKY-WATCHING TOOL**

**Moon Gazers’ Wheel.**
Produced by Celestial Products, package of two Moon Gazers’ Wheels, $14.95. [www.mooncalendar.com](http://www.mooncalendar.com)

The Moon Gazers’ Wheel is simple to use. Just look at the Moon in the sky and turn the wheel to match what you see. From there you can read information about rise and set times, age of the Moon, name of the phase, etc., around the wheel. The wheel is 17.8 centimeters by 22.9 centimeters (7 inches by 9 inches) and made in the U.S. It shows the name of the phase (waning gibbous, waxing crescent, etc.), the Moon’s position in orbit and day of the lunar month, the relative Sun direction and period of day/night Moon is in the sky, and Moon rise and Moon set rudimentary times.
New and Noteworthy continued...

FOR KIDS!!!

50 Things You Should Know About Space.
By Raman Prinja. Quarto Publishing Group, 2016, 80 pp., Paperback. $15.95. www.quartoknows.com

What exactly goes on at the International Space Station and why does the Earth spin? Just how big is our galaxy and how did the Moon form? From constellations to space shuttles, space is as endlessly fascinating as the universe itself. Discover everything you ever wanted to know about space missions, colliding galaxies, light years, solar eclipses, the surface of the Sun, and much, much more in this exciting title. Packed with facts and figures, you’ll also find out about astronomers, astronauts, and scientists and how their incredible jobs have enabled us to learn so much about our universe. For ages 8 to 12.

Math on Mars. By Mark Harasymiw.
Gareth Stevens Publishing, 2016, 24 pp., Hardcover. $22.60. www.garethstevens.com

Mars is perhaps the most thrilling planet these days in the minds of the public. With rovers exploring its surface and manned missions in the works, people are wondering if Mars is our next home. In this high-interest book, readers will learn more about Earth’s neighbor, including what its climate and surface are like, why it’s called the Red Planet, and about the recent discovery of water on its surface. They’ll learn all this while solving Your Mission math problems that complement and support the text. This motivating volume is an engaging way to explore key aspects of science and math curricula. For ages 7 to 10.

Juno Spacecraft Paper Model.

Build your own scale model of Juno, the sophisticated spacecraft currently investigating Jupiter’s elemental composition, gravity field, magnetic field, and more. This paper model guide has assembly instructions and parts sheets. A color printer, some thick white paper, and a few other items are required. Assembly of this detailed model requires several hours and great care. This model was designed in 2011 by John Jogerst and adapted for NASA distribution by David Doody at the Jet Propulsion Laboratory. For ages 10 and up.
Planets: A LEGO® Adventure in the Real World.
By Penelope Arlon and Tory Gordon-Harris. Scholastic, 2016, 64 pp., Paperback. $8.99. new.scholastic.com

Blast off with the LEGO® minifigures through our solar system and beyond! See incredible stars and planets and find out the latest space facts — from water on Mars to Planet X. The LEGO® minifigures put the fun into facts. There are great building ideas, too. This book is part of a program of LEGO® nonfiction books, with something for all the family, at every age and stage. These books have amazing facts, beautiful real-world photos, and minifigures everywhere, leading the fun and discovery. For ages 6 to 8.
Calendar 2016–2017

For the latest version of the meeting calendar, visit http://www.hou.usra.edu/meetings/calendar.

October

6  MEPAG Meeting #32, Pasadena, California. http://mepag.nasa.gov/meetings.cfm?expand=m32
10–14 The Seventh Moscow Solar System Symposium (7M-S3), Moscow, Russia. http://ms2016.cosmos.ru/
16–21 Joint 48th Division of Planetary Sciences (DPS) and 11th European Planetary Science Conference (EPSC), Pasadena, California. http://aas.org/meetings/dps48

November

14–16 High-Contrast Imaging in Space, Baltimore, Maryland. http://www.cvent.com/d/5fqdv1
29–Dec 1 14th Meeting of the Venus Exploration Analysis Group (VEXAG), Washington, DC. http://www.lpi.usra.edu/vexag/

December

### January 2017

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<tr>
<td>11–13</td>
<td>Dust, Atmosphere, and Plasma Environment of the Moon and Small Bodies (DAP 2017), Boulder, Colorado.</td>
<td><a href="http://impact.colorado.edu/dap_meeting.html">http://impact.colorado.edu/dap_meeting.html</a></td>
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<td>20–24</td>
<td>Science with the Hubble and James Webb Telescopes V</td>
<td>Venice, Italy.</td>
<td><a href="http://www.stsci.edu/institute/conference/hst5">http://www.stsci.edu/institute/conference/hst5</a></td>
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<td>20–24</td>
<td>Astrochemistry VII — Through the Cosmos from Galaxies to Planets</td>
<td>Purto Varas, Chile.</td>
<td><a href="https://www.iau.org/science/meetings/future/symposia/1187/">https://www.iau.org/science/meetings/future/symposia/1187/</a></td>
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<td>22–26</td>
<td>Astrophysics of Exoplanetary Atmospheres</td>
<td>Vietri sul Mare, Italy.</td>
<td><a href="http://www.mpia.de/~mancini/as2es">http://www.mpia.de/~mancini/as2es</a></td>
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