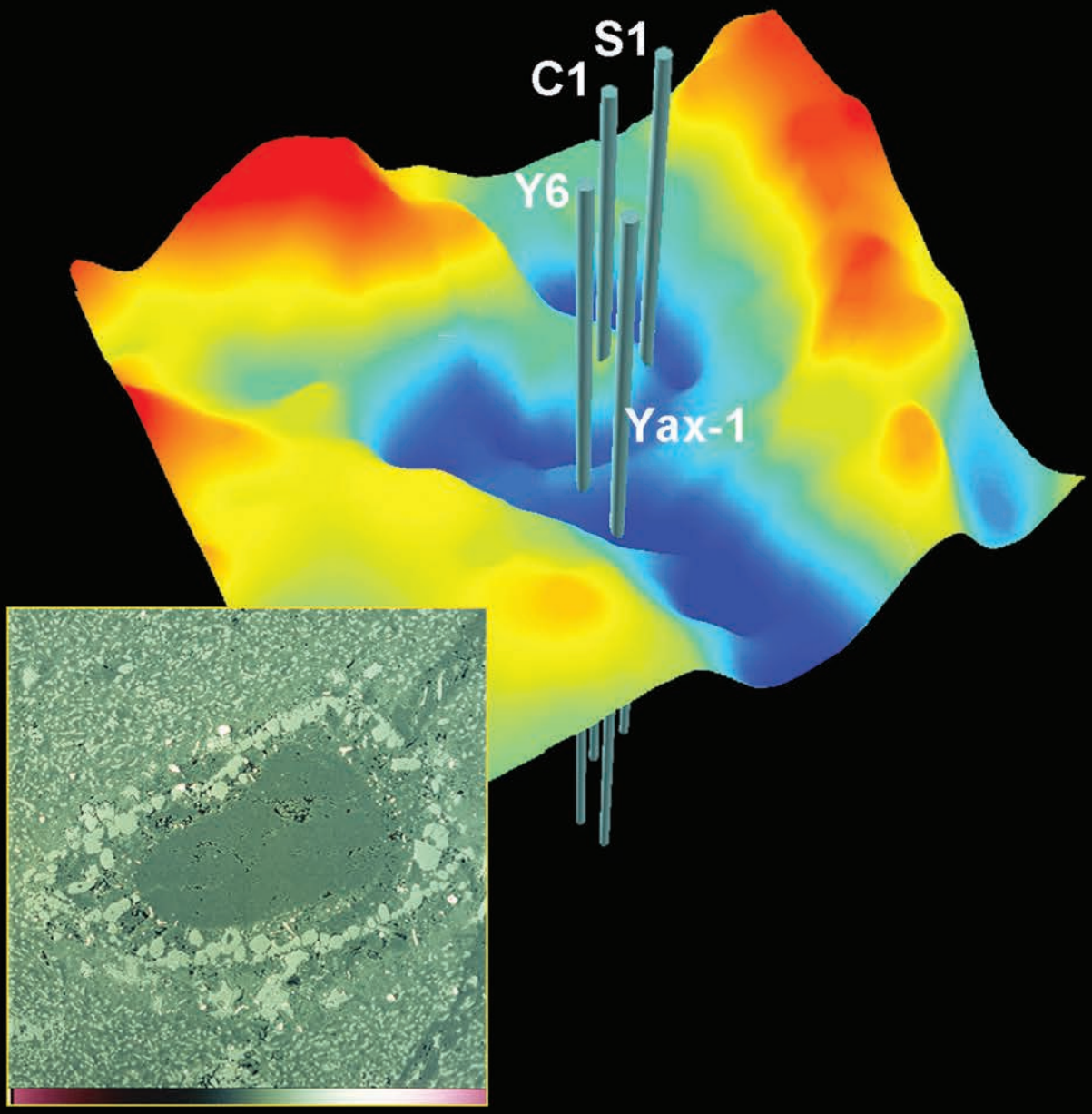
Chicxulub Crater,
TWENTY-FIVE YEARS LATER



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Chicxulub Crater, Twenty-Five Years Later

— David A. Kring, Lunar and Planetary Institute

The Chicxulub impact event in eastern Mexico is infamous for the devastation it wrought to planet Earth. This 180-kilometer-diameter impact structure is contemporaneous with the largest mass extinction event during the past 100 million years, and is almost certainly responsible for the demise of dinosaurs and most life on Earth 66 million years ago, abruptly ending the 186-million-year-long Mesozoic Era.

Twenty-five years after evidence of its impact origin was presented at the 22nd Lunar and Planetary Science Conference (LPSC) in Houston, the link between the Chicxulub crater and the Cretaceous/Tertiary (K/T, or K/Pg) boundary events has been verified multiple times and, with the site of the impact identified, a better assessment of the profound global impact-generated environmental effects followed.

Interestingly, the subsurface Chicxulub structure, buried beneath ~1 kilometer of sediment, was identified decades earlier using geophysical techniques and exploration boreholes drilled in search of petroleum, the latter of which located what was interpreted to be intrusive and extrusive andesite with pyroclastic tuff. As divulged during an oral session at the 22nd LPSC in 1991, we learned that the melt rocks and breccias within the structure are not the product of magmatic intrusions and extrusions as previously interpreted, but rather the consequences of an impacting near-Earth asteroid (or possibly comet) with a kinetic energy equivalent to ~100 million megatons of TNT (Fig. 1). The breccias covering the upper Cretaceous elsewhere on the Yucatán Peninsula were neither volcanic materials nor debris eroded from tectonic uplifts as previously presumed, but rather products of >10,000 cubic kilometers of debris ejected from a crater. The confusion between volcanism and impacts that vexed the field of impact cratering a hundred years ago also confounded the discovery of the Chicxulub crater.

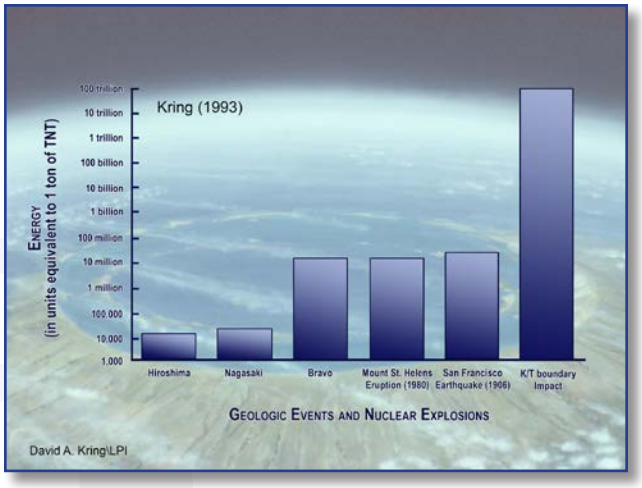

Fig. 1. The energy of the K/T boundary impact event compared to several other geologic events and nuclear explosions, including Bravo, the United States' largest nuclear test explosion. Credit: Adapted from Kring [(1993) The Chicxulub impact event and possible causes of K/T boundary extinctions, in Proceedings of the First Annual Symposium of Fossils of Arizona (D. Boaz and M. Dornan, eds.), pp. 63–79, Mesa Southwest Museum and the Southwest Paleontological Society, Mesa]. Background art by William K. Hartmann (©1991), used with permission.

Evidence linking the Chicxulub crater with impact ejecta in the K/T boundary layers include a crater-filling impact melt with a similar chemical composition and radiometric age as impact melt spherules deposited at the K/T boundary in Haiti; an ejecta thickness at the boundary that decreases radially away from the Chicxulub crater; shocked quartz grain sizes in boundary sediments that decrease with radial distance from the Chicxulub crater; shocked quartz, feldspar, and lithic fragments in boundary sediments similar to Chicxulub basement rocks; unshocked zircon in boundary sediments that are consistent with the age of Chicxulub

basement rocks; and shocked zircon in boundary sediments with the same age as the Chicxulub crater. The projectile that produced the crater had affinities with carbonaceous chondritic meteorites and was the source of the iridium anomaly in K/T boundary sediments (Fig. 2) that initially prompted the impact-mass extinction hypothesis and the search for a crater.

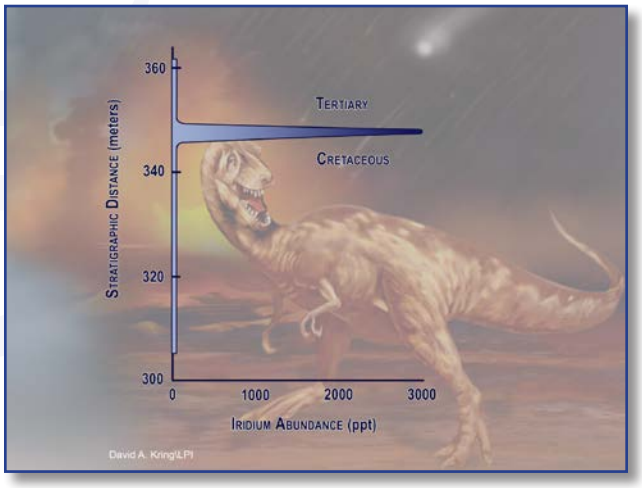

Fig. 2. A profile of iridium abundance in a stratigraphic column of sediments from Gubbio (Italy) that includes an anomalously high value at the K/T boundary. Credit: Data from W. Alvarez et al. [(1990) Iridium profile for 10 million years across the Cretaceous-Tertiary boundary at Gubbio (Italy), Science, 250, 1700–1702]; illustration adapted from Kring [(1993) The Chicxulub impact event and possible causes of K/T boundary extinctions, in Proceedings of the First Annual Symposium of Fossils of Arizona (D. Boaz and M. Dornan, eds.), pp. 63–79, Mesa Southwest Museum and the Southwest Paleontological Society, Mesa].

The impact occurred on a submerged portion of the Yucatán carbonate shelf surrounded by the Gulf of Mexico and the Caribbean Sea. The seas and near-shore deltaic systems were teeming with rudist and coral reefs, oysters, giant inoceramid clams, ammonites, bryozoans, gastropods, and crabs, many of which are found fossilized in K/T boundary sediments bounding the region. Those waters were haunted by ferocious mosasaurs, with different species ranging from 4 to 15 meters in length, hungrily feeding on ammonites, fish, and even smaller mosasaurs, before being extinguished forever by the impact event. Ubiquitous were foraminerfera, single-celled organisms with fascinating little shells, floating in the water column or inhabiting the sea floor, consuming diatoms, bacteria, algae, a type of crustacean called copepods, and other tiny detritus.

After a brilliant flash of light and heat that was quickly followed by shock waves and an air blast that roared over the surface, sea waves radiated across the Gulf of Mexico, cutting down into reefs, burying the seafloor with both impact ejecta and tsunami backwash deposits, including one that entrained a dismembered mosasaur. In some areas, seismically triggered landslides of submerged slope sediments roared down to cover deeper parts of the basin with vast breccia and turbidite deposits. The Chicxulub impact event was one of the largest geologic displacements of rock and sediment to occur across Earth's surface during the Phanerozoic, and that displacement occurred nearly instantaneously.

As devastating as those regional impact effects were, they were not responsible for the mass extinction that characterizes the K/T boundary. Rather, the global extinctions were driven by the distribution of ejecta, including climate-altering gases, that encircled the planet. The discovery of the Chicxulub impact site, which was covered with a sequence of carbonate and evaporite sediments, led to tremendous improvements in model calculations of its catastrophic effects.

The presence of anhydrite ($CaSO_4$) deposits in target rocks was not anticipated and immediately altered estimates of the environmental effects of the K/T impact, which had often been assumed to be in the deep

ocean prior to the discovery of Chicxulub. Model calculations of a shock-heated atmosphere implied the production of nitric acid rain, but that model of precipitation was now compounded by the addition of sulfur chemistry. After discovering Chicxulub, it was clear that vaporized anhydrite was injected into the stratosphere, producing sulfate aerosols and eventually sulfuric acid rain, affecting shallow freshwater systems and estuaries and chemically leaching soils.

When ejecta carried into space by an expanding and accelerating vapor-rich impact plume reaccreted to the top of the atmosphere, it heated the atmosphere and, in some areas, heated the surface of Earth so severely that it ignited wildfires. The distribution of those fires is still debated and depends, in part, on the trajectory of the impactor, which is also still being debated. Those fires pumped greenhouse-warming carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4) into the atmosphere in proportions equal to or greater than that produced by vaporizing the carbonate target sediments at the Chicxulub site. They also released ozone-destroying chlorine, bromine, and fluorine, which, when combined with contributions from the projectile and target lithologies, greatly exceeded the threshold needed to destroy the ozone layer.

Initially surface temperatures across our planet rose when the atmosphere was heated by impact ejecta zipping through the atmosphere, then cooled by debris in the atmosphere that blocked sunlight and shut down photosynthetic organisms at the base of the food chain. It took 5 to 10 years for dust and aerosols to settle out of the atmosphere, after which surface temperatures rose due to the greenhouse gases ejected into the atmosphere. While many scientists in the community have been working to understand those processes in light of the discovery of Chicxulub, it is also important to note that several investigators are still pursuing potential volcanic crises for the mass extinction event, either spawned independently by the Deccan eruptions in India or catalyzed by a Chicxulub-enhanced extrusion rate in the Deccan province.

Although our attention is often riveted by the catastrophic environmental and biological consequences of the Chicxulub impact, the crater has also been a focus of study because it is a magnificent geologic structure. It is the best preserved peak-ring or multi-ring basin on Earth. That preservation is ensured, in part, by the tectonic stability of the Yucatán Peninsula and Tertiary sediments that blanket the structure. The challenge for geologists is to penetrate those sediments, which are up to ~1 kilometer thick, to reach the crater.

The first targeted effort to probe the crater was the Chicxulub Scientific Drilling Project of 2001–2002, which was sponsored by the International Continental Drilling Program (ICDP). That project bottomed at 1511 meters and recovered over 1100 meters of core from an impactite-filled trough between the peak ring of the basin and the modification zone of collapsed target rocks that expanded the crater to its final diameter. That project provided the first continuous core through an impactite sequence in the crater and provided samples of underlying target sedimentary rocks that had collapsed inward. It also provided a spectacular spatial and temporal measure of a post-impact hydrothermal system.

Beginning in April of this year, a second effort to probe the crater — this time into the peak ring — will be launched by the International Ocean Discovery Program (IODP) in collaboration with ICDP.

Expedition 364 Chicxulub Impact Crater project (Fig. 3) is a Mission Specific Platform Expedition, meaning it is being drilled from a platform specially selected for the project, rather than IODP's Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) Resolution or Chikyu scientific drilling ships. The selected drilling site is in an area with ecologically sensitive reefs and a shallow water depth of 17 to 18 meters, which calls for specialized equipment.

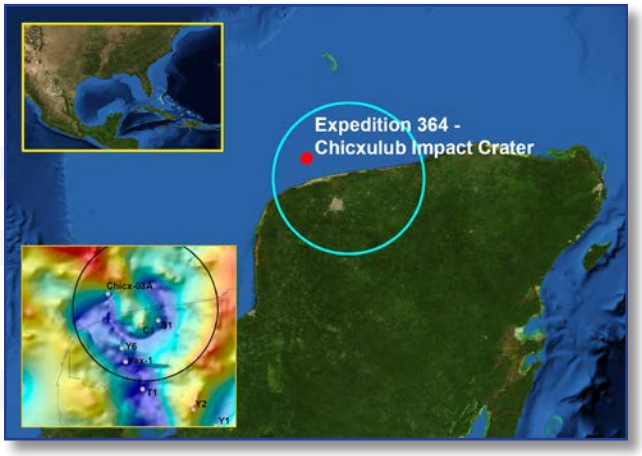

Fig. 3. A joint IODP-ICDP borehole will be drilled ~30 kilometers northwest of Progreso and the north shore of the Yucatán Peninsula of Mexico. That borehole, labeled Chicx-03A on a gravity map (inset), will target the peak ring in that quadrant of the crater. Credit: David A. Kring/LPI.

Sixty days are planned for drilling, coring, and downhole measurements in April and May. The drilling goal is to reach a depth of 1200 to 1500 meters and recover ~500 meters, possibly more, of peak ring rocks. Core logging by the science party is scheduled for September and October.

The scientific goals of the project include an assessment of peak-ring lithologies and how they may have been deformed and thus flowed during the cratering event. This information is critical in order to effectively test models of peak ring formation (Fig. 4). Those models are guided in part by observations of similar structures, such as the exquisitely exposed Schrödinger basin on the Moon (Fig. 5), but need to be evaluated with core samples from Chicxulub and, ideally, field geology on the lunar surface at some point in the near future.

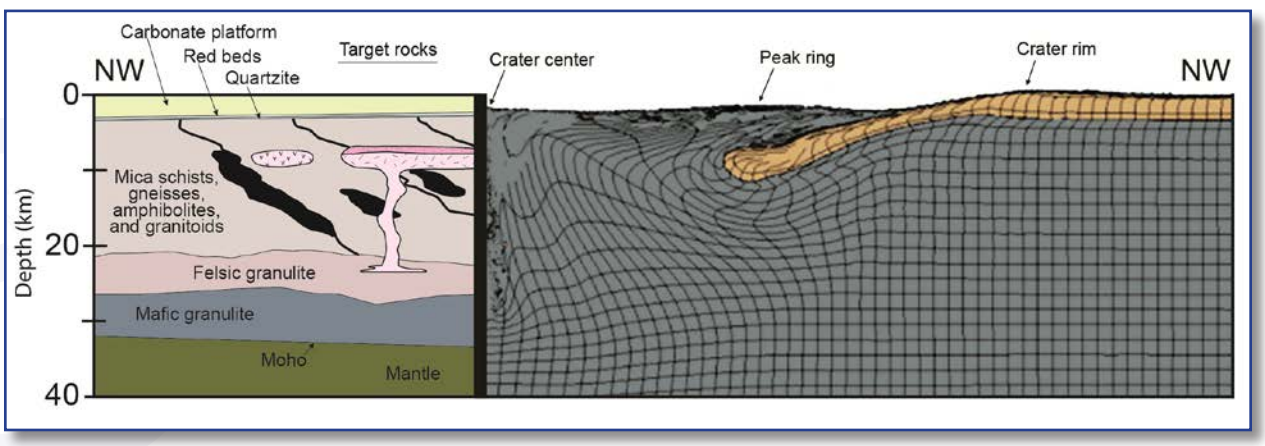

Fig. 4. A key objective of Expedition 364 is to test models of peak ring formation. On the left is a schematic diagram of the target [adapted from Kring (2005), Chemie der Erde, 65, 1–46] and on the right is a hydrocode simulation [Collins et al. (2008), Earth and Planetary Science Letters, 270, 221–230] where an uplifted central peak collapsed outward to form the peak ring. In an alternative model, the peak ring is uplifted directly from the walls of the transient crater cavity. Although horizontal lines appear on the right to track rock flow in the simulation, it is important to understand that the upper part of the crystalline basement in the target is not stratified, but rather composed of a tectonized assemblage of metamorphic rocks intruded by granitic magmas as shown on the left.

Fig. 5. The most dramatic impact event during the past half-billion years is the Chicxulub impact (inset, bottom center), which extinguished dinosaurs (inset, lower left) and most life on Earth at the K/T boundary 66 million years ago. The ~180-kilometer-diameter Chicxulub crater (left background) is the best-preserved example of a peak-ring basin on Earth, but it is buried beneath Tertiary sediments. To help understand the formation of that type of impact basin, geologists also study analog structures, such as the magnificently exposed Schrödinger basin on the lunar farside (right background) that formed ~3.8 billion years ago (inset, lower right). Credit: Background art, left, by William K. Hartmann (©1991), used with permission. Background illustration, right, produced by NASA GSFC's Scientific Visualization Studio. Insets (left to right) produced by LPI, William K. Hartmann (©1983), and Daniel D. Durda (©2011). This educational illustration is being released as part of the LPI's Never Stop Exploring series.

The drilling project will also measure the hydrothermal alteration in the peak ring and physical properties, such as permeability, needed to (1) further test models of impact-generated hydrothermal systems, (2) evaluate the habitability of the peak ring, and (3) investigate the recovery of life in a sterile zone. The nature and composition of any impact breccias and melt rocks, including any dikes in the peak ring, will be analyzed. An assessment of target lithologies will also be made to fine-tune estimates of the impact's climatic effects.

Finally, studies of the core and correlative downhole measurements will provide a calibration point for crater-wide geophysical imaging of the subsurface, greatly enhancing future three-dimensional application of those geophysical techniques to the entire impact basin. To fully understand the Chicxulub crater, however, it has been estimated that a total of six to eight boreholes will be needed to fully extract the geological details preserved in this fascinating structure. Thus, while the research done on this

geologic structure over the past 25 years has yielded countless insightful results, it is clear that many secrets remain buried beneath the sediments of the Yucatán Peninsula, waiting to be revealed by the next generation of researchers.

Acknowledgements.

Hundreds of scientists have contributed to our understanding of Chicxulub and the K/T boundary events described above. Their work is gratefully acknowledged. For students wanting to access that literature and other information, the following publications are recommended:

- For marine K/T boundary sequences: J. Smit (1999) A*nnual Reviews of Earth and Planetary Science,* 27, 75–113.
- For crater lithologies: D. A. Kring (2005) *Chemie der Erde*, 65, 1–46.
- For links between Chicxulub and K/T boundary sediments: D. A. Kring (2007) *Palaeogeography, Palaeoclimatolology, and Palaeoecology*, 255, 4–21; P. Schulte et al. (2010) *Science*, 327, 1214–1218.
- For structural models integrating geophysical measurements and hydrocode simulations: J. V. Morgan et al. (2011) *Journal of Geophysical Research*, 116, B06303, 14 pp.
- For a popular science article: D. A. Kring and D. D. Durda (2003) The day the world burned, *Scientific American*, 289(6), 98–105.

LPI has posted additional online resources at *http://www.lpi.usra.edu/science/kring/epo_web/impact_cratering/Chicxulub*.

About the Author:

Dr. David Kring is a senior staff scientist at the Lunar and Planetary Institute in Houston, Texas. He has worked extensively with the Chicxulub impact crater and the Cretaceous-Tertiary mass extinction event. He has also studied, more broadly, the geologic processes associated with impact cratering and their environmental and biological consequences throughout Earth history, including an inner solar system bombardment that occurred more than 3.5 billion years ago. He is currently the Principal Investigator of the LPI-JSC Center for Lunar Science and Exploration, through which he is integrating his field experience in impact-cratered and volcanic terrains with his analytical experience of Apollo, Luna, and meteorite sample collections to assist training and mission simulations needed to advance the nation's human and robotic exploration programs.

About the Cover:

The locations of boreholes drilled into the Chicxulub crater are superimposed on a gravity map of the crater. Yucatán-6 (Y6) is the discovery hole in which shocked quartz, shocked feldspar, and impact melt were found. Two other petroleum exploration boreholes are Chicxulub-1 (C1) and Sacapuc-1 (S1). The first scientific borehole with continuous core was Yaxcopoil-1 (Yax-1). The inset is a backscattered-electron (BSE) image of relict quartz in the discovery borehole, surrounded by a corona of augite and feldspar, in the impact melt, which was subsequently cross-cut with a hydrothermal quartz vein. Credit: Gravity map by David A. Kring and Lukas Zurcher; BSE image by David A. Kring.

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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's LADEE Mission Shows the Force of Meteoroid Strikes on Lunar Exosphere

Artist's concept of NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft in orbit above the Moon. Credit: NASA Ames/Dana Berry.

NASA scientists have released new findings about the Moon's tenuous exosphere — the thin layer of gas surrounding the Moon that is one 25-trillionth the density of Earth's atmosphere. The data reveal, for the first time, that meteoroid strikes cause a predictable increase in the abundance of two key elements within the lunar exosphere.

Physical processes such as meteoroid stream impacts, the bombardment of helium and hydrogen particles from the Sun, thermal absorption, and space weathering constantly modify the Moon's surface as they work within the lunar exosphere. NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft observed an increase in exospheric gases when the rain of meteoroid impacts increases during a stream. These interplanetary grains can hit the lunar surface at speeds exceeding 34 kilometers (21 miles) per second, releasing immense heat, and vaporizing part of the soil and meteoroids themselves.

Within this vapor are sodium and potassium gases. LADEE's Ultraviolet Visible Spectrometer (UVS) instrument measured levels of sodium and potassium around the Moon every 12 hours for more than 5 months. These frequent readings revealed a dynamic rise of gas levels in the exosphere as meteor streams bombarded the Moon, with the concentrations of both elements returning to normal background levels after the stream passed. Interestingly, the time it took to return to "normal" was dramatically different for the two gases, with potassium returning to its pre-shower state within days, while sodium took several months.

The findings appeared in the journal *Science.* Researchers will incorporate these observations into exosphere models of the Moon and similar bodies to help NASA unravel the mysteries of how our solar system originated and is changing over time.

"To understand the Moon's exosphere requires insight into the processes controlling it, including the interaction of meteoroid showers as well as solar wind bombardment and ultraviolet radiation of the surface," said Anthony Colaprete, researcher at NASA's Ames Research Center in Moffett Field, California, and principal investigator of the UVS instrument. "Understanding how these processes modify the exosphere allows researchers to infer its original state. Since these processes are ubiquitous across the solar system, knowledge gained by examining the Moon's exosphere can be applied to a range of other bodies, granting us greater insight into their evolution through time."

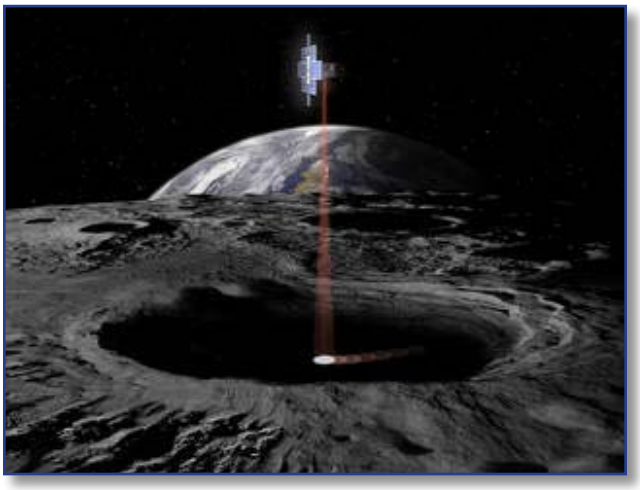
A majority of bodies in the solar system are small and are considered "airless," with exospheres in place of dense atmospheres. Our Moon, icy moons within our solar system, the planet Mercury, asteroids, and even Pluto are examples of small bodies with known exospheres that start from their surface —

surface-boundary exospheres. Larger bodies, such as Earth, also have tenuous exospheres as the outermost layer of their atmospheres.

Our Moon can act as a nearby laboratory for learning more about both the soil composition and the processes actives in the atmospheres across our solar system and beyond.

LADEE was launched in September 2013 and orbited the Moon for about six months. The robotic mission orbited the Moon to gather detailed information about the lunar atmosphere, conditions near the surface, and environmental influences on lunar dust. For more information, visit *http://www.nasa.gov/ladee.*

NASA Space Launch System's First Flight to Send Small Sci-Tech Satellites Into Space



The Lunar Flashlight, flying as secondary payload on the first flight of NASA's Space Launch System, will examine the Moon's surface for ice deposits and identify locations where resources may be extracted. Credit: NASA.

The first flight of NASA's new rocket, the Space Launch System (SLS), will carry 13 CubeSats to test innovative ideas along with an uncrewed Orion spacecraft in 2018. These small satellite secondary payloads will carry science and technology investigations to help pave the way for future human exploration in deep space, including the journey to Mars. SLS' first flight, referred to as Exploration Mission-1 (EM-1), provides the rare opportunity for these small experiments to reach deep space destinations, as most launch opportunities for CubeSats are limited to low-Earth orbit. "The 13 CubeSats that will fly to deep space as secondary payloads aboard SLS on EM-1 showcase the intersection of science and technology, and advance our journey to Mars," said NASA Deputy Administrator Dava Newman.

The secondary payloads were selected through a series of announcements of flight opportunities, a NASA challenge and negotiations with NASA's international partners. "The SLS is providing an incredible opportunity to conduct science missions and test key technologies beyond low-Earth orbit," said Bill Hill, deputy associate administrator for Exploration Systems Development at NASA Headquarters in Washington. "This rocket has the unprecedented power to send Orion to deep space plus room to carry 13 small satellites — payloads that will advance our knowledge about deep space with minimal cost."

NASA selected two payloads through the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement:

- Skyfire: Lockheed Martin Space Systems Company, Denver, Colorado, will develop a CubeSat to perform a lunar flyby of the Moon, taking sensor data during the flyby to enhance our knowledge of the lunar surface

- Lunar IceCube: Morehead State University, Kentucky, will build a CubeSat to search for water ice and other resources at a low orbit of only 100 kilometers (62 miles) above the surface of the Moon

Three payloads were selected by NASA's Human Exploration and Operations Mission Directorate:

- Near-Earth Asteroid Scout (NEA Scout) will perform reconnaissance of an asteroid, take pictures, and observe its position in space
- BioSentinel will use yeast to detect, measure, and compare the impact of deep space radiation on living organisms over long durations in deep space
- Lunar Flashlight will look for ice deposits and identify locations where resources may be extracted from the lunar surface

Two payloads were selected by NASA's Science Mission Directorate:

- CuSP, a "space weather station" to measure particles and magnetic fields in space, testing practicality for a network of stations to monitor space weather
- LunaH-Map, which will map hydrogen within craters and other permanently shadowed regions throughout the Moon's south pole

Three additional payloads will be determined through NASA's Cube Quest Challenge — sponsored by NASA's Space Technology Mission Directorate and designed to foster innovations in small spacecraft propulsion and communications techniques. CubeSat builders will vie for a launch opportunity on SLS' first flight through a competition that has four rounds, referred to as ground tournaments, leading to the selection in 2017 of the payloads to fly on the mission. NASA has also reserved three slots for payloads from international partners.

On this first flight, SLS will launch the Orion spacecraft to a stable orbit beyond the Moon to demonstrate the integrated system performance of Orion and the SLS rocket prior to the first crewed flight. The first configuration of SLS that will fly on EM-1 is referred to as Block I and will have a minimum 70-metric-ton (77-ton) lift capability and be powered by twin boosters and four RS-25 engines. The CubeSats will be deployed following Orion separation from the upper stage and once Orion is a safe distance away. Each payload will be ejected with a spring mechanism from dispensers on the Orion stage adapter. Following deployment, the transmitters on the CubeSats will turn on, and ground stations will listen for their beacons to determine the functionality of these small satellites.

Opportunity Mars Rover Goes Six-Wheeling up a Ridge

NASA's senior Mars rover, Opportunity, is working adeptly in some of the most challenging terrain of the vehicle's 12 years on Mars, on a slope of about 30°. Researchers are using Opportunity to examine rocks that may have been chemically altered by water billions of years ago. The mission's current targets of investigation are from ruddy-tinted swaths the researchers call "red zones," in contrast to tan bedrock around these zones. The targets lie on "Knudsen Ridge," atop the southern flank of "Marathon Valley," which slices through the western rim of Endeavour Crater. A panorama of Knudsen Ridge is online at *http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA20319.*

This scene from NASA's Mars Exploration Rover Opportunity looks upward at "Knudsen Ridge" from the valley below. Credit: NASA/JPL-Caltech/Cornell Univ./ Arizona State Univ.

"We're hoping to take advantage of the steep topography that Mars provides us at Knudsen Ridge to get to a better example of the red zone material," said Steve Squyres of Cornell University, Ithaca, New York, principal investigator for the mission. The red zone material crumbles easily. At locations in Marathon Valley where Opportunity already got a close look at it, the reddish bits are blended with other loose material accumulating in low locations. A purer exposure of the red zone material, such as some apparent on the ridge, would provide a better target for the Alpha Particle X-ray Spectrometer on Opportunity's arm, which reveals the chemical composition of rocks and soil.

Opportunity began climbing Knudsen Ridge in late January with two drives totaling 9.4 meters (31 feet). The wheels slipped less than 20% up slopes as steep as 30°, the steepest the rover has driven since its first year on Mars in 2004. The slip is calculated by comparing the distance the rotating wheels would have covered if there were no slippage to the distance actually covered in the drive, based on "visual odometry" imaging of the terrain the rover passes as it drives.

"Opportunity showed us how sure-footed she still is," said Mars Exploration Rover Project Manager John Callas at NASA's Jet Propulsion Laboratory, Pasadena, California. "The wheel slip has been much less than we expected on such steep slopes." The rover made additional progress toward targets of red-zone material on Knudsen Ridge with a drive on February 18.

Knudsen Ridge forms a dramatic cap overlooking the 22-kilometer-wide (14-mile-wide) Endeavour Crater. Its informal naming honors the memory of Danish astrophysicist and planetary scientist Jens Martin Knudsen (1930–2005), a founding member of the science team for Opportunity and the twin rover Spirit. "This ridge is so spectacular, it seemed like an appropriate place to name for Jens Martin," Squyres said.

Marathon Valley became a high-priority destination for the Opportunity mission when mineral-mapping observations by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), onboard NASA's Mars Reconnaissance Orbiter, located clay minerals (a type of phyllosilicate) in this valley. Clay minerals often form in the presence of water, which is why this is such a promising area of exploration. Opportunity found evidence of ancient water shortly after landing, but there were signs that the water would have been more highly acidic. The investigation in Marathon Valley could add understanding about the ancient environmental context for the presence of non-acidic water, a factor favorable for microbial life, if any has ever existed on Mars.

"The locations of red zones in Marathon Valley correlate closely with the phyllosilicate signature we see from orbit," Squyres said. "That alone is not a smoking gun. We want to determine what it is about their chemistry that sets them apart and what it could have to do with water."

To test the idea that water affected the red zone material, the experiment underway aims to compare the chemistry of that material to the chemistry of the surrounding tan bedrock, which could represent an unaltered baseline. Opportunity used its diamond-toothed rock abrasion tool last month to scrape the crust off a tan bedrock target for an examination of the chemistry inside the rock.

The team is accomplishing productive science with Opportunity while avoiding use of the rover's flash memory, which was linked to several unplanned computer reboots last year. The only data being received from Opportunity is what can be transmitted each day before the solar-powered rover shuts down for energy-conserving overnight "sleep." For more information, visit *http://www.nasa.gov/rovers* and *http://marsrovers.jpl.nasa.gov.*

New Animation Takes a Colorful Flight Over Ceres

A colorful new animation shows a simulated flight over the surface of dwarf planet Ceres, based on images from NASA's Dawn spacecraft. The movie shows Ceres in enhanced color, which helps to highlight subtle differences in the appearance of surface materials. Scientists believe areas with shades of blue contain younger, fresher material, including flows, pits, and cracks.

Simulated view of Dwarf planet Ceres using images from NASA's Dawn spacecraft. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA.

The animated flight over Ceres emphasizes the most prominent craters, such as Occator, and the tall, conical mountain Ahuna Mons. Features on Ceres are named for earthly agricultural spirits, deities, and festivals. The movie was produced by members of Dawn's framing camera team at the German Aerospace Center (DLR), using images from Dawn's high-altitude mapping orbit. During that phase of the mission, which lasted from August to October 2015, the spacecraft circled Ceres at an altitude of about 1450 kilometers (900 miles).

"The simulated overflight shows the wide range of crater shapes that we have encountered on Ceres. The viewer can observe the sheer walls of the crater Occator, and also Dantu and Yalode, where the craters are a lot flatter," said Ralf Jaumann, a Dawn mission scientist at DLR.

Dawn is the first mission to visit Ceres, the largest object in the main asteroid belt between Mars and Jupiter. After orbiting asteroid Vesta for 14 months in 2011 and 2012, Dawn arrived at Ceres in March 2015. The spacecraft is currently in its final and lowest mapping orbit, at about 385 kilometers (240 miles) from the surface.

For more information or to view the video, visit *http://www.nasa.gov/dawn* and *http://dawn.jpl.nasa.gov*.

Juno Spacecraft Breaks Solar Power Distance Record

NASA's Juno mission to Jupiter has broken the record to become humanity's most distant solar-powered emissary. The milestone occurred on Wednesday, January 13, when Juno was about 793 million kilometers (493 million miles) from the Sun. The previous record-holder was the European Space Agency's Rosetta spacecraft, whose orbit peaked out at the 792-million-kilometer (492-million-mile) mark in October 2012, during its approach to Comet 67P/Churyumov-Gerasimenko.

This artist's concept depicts the Juno spacecraft, which launched from Earth in 2011 and will arrive at Jupiter in 2016 to study the giant planet from an elliptical, polar orbit. Juno will repeatedly dive between the planet and its intense belts of charged particle radiation, coming only 5000 kilometers (about 3000 miles) from the cloud tops at closest approach. Credit: NASA/JPL-Caltech.

"Juno is all about pushing the edge of technology to help us learn about our origins," said Scott Bolton, Juno principal investigator at the Southwest Research Institute in San Antonio. "We use every known technique to see through Jupiter's clouds and reveal the secrets Jupiter holds of our solar system's early history. It just seems right that the Sun is helping us learn about the origin of Jupiter and the other planets that orbit it."

Launched in 2011, Juno is the first solar-powered spacecraft designed to operate at such a great distance from the Sun. That's why the surface area of solar panels required to generate adequate power is quite large. The four-ton Juno spacecraft carries three 9-meter-long (30-foot-long) solar arrays festooned with 18,698 individual solar cells. At Earth distance from the Sun, the cells have the potential to generate approximately 14 kilowatts of electricity. But transport those same rectangles of silicon and gallium arsenide to a fifth rock from the Sun distance, and it's a powerfully different story.

"Jupiter is five times farther from the Sun than Earth, and the sunlight that reaches that far out packs 25 times less punch," said Rick Nybakken, Juno's project manager from NASA's Jet Propulsion Laboratory in Pasadena, California. "While our massive solar arrays will be generating only 500 watts when we are at Jupiter, Juno is very efficiently designed, and it will be more than enough to get the job done."

Prior to Juno, eight spacecraft have navigated the cold, harsh underlit realities of deep space as far out as Jupiter. All have used nuclear power sources to get their job done. Solar power is possible on Juno due to improved solar-cell performance, energy-efficient instruments and spacecraft, a mission design that can avoid Jupiter's shadow, and a polar orbit that minimizes the total radiation. Juno's maximum distance from the Sun during its 16-month science mission will be about 832 million kilometers (517 million miles), an almost 5% increase in the record for solar-powered space vehicles.

Juno will arrive at Jupiter on July 4 of this year. Over the next year the spacecraft will orbit the jovian world 33 times, skimming to within 5000 kilometers (3100 miles) above the planet's cloud tops every 14 days. During the flybys, Juno will probe beneath the obscuring cloud cover of Jupiter and study Jupiter's aurorae to learn more about the planet's origins, structure, atmosphere, and magnetosphere. For more information, visit *http://www.nasa.gov/juno* and *https://www.missionjuno.swri.edu*.

Saturn's Rings: Less than Meets the Eye?

It seems intuitive that an opaque material should contain more stuff than a more translucent substance. For example, muddier water has more suspended particles of dirt in it than clearer water. Likewise, you might think that, in the rings of Saturn, more opaque areas contain a greater concentration of material than places where the rings seem more transparent. But this intuition does not always apply, according to a recent study of the rings using data from NASA's Cassini mission. In their analysis, scientists found surprisingly little correlation between how dense a ring might appear to be — in terms of its opacity and reflectiveness — and the amount of material it contains. The new results concern Saturn's B ring, the brightest and most opaque of Saturn's rings, and are consistent with previous studies that found similar results for Saturn's other main rings.

Saturn's B ring is the most opaque of the main rings, appearing almost black in this Cassini image taken from the unlit side of the ringplane. Credit: NASA/JPL-Caltech/ Space Science Institute.

The scientists found that, while the opacity of the B ring varied by a large amount across its width, the mass — or amount of material — did not vary much from place to place. They "weighed" the nearly

opaque center of the B ring for the first time — technically, they determined its mass density in several places — by analyzing spiral density waves. These are fine-scale ring features created by gravity tugging on ring particles from Saturn's moons, and the planet's own gravity. The structure of each wave depends directly on the amount of mass in the part of the rings where the wave is located.

"At present it's far from clear how regions with the same amount of material can have such different opacities. It could be something associated with the size or density of individual particles, or it could have something to do with the structure of the rings," said Matthew Hedman, the study's lead author and a Cassini participating scientist at the University of Idaho, Moscow. Cassini co-investigator Phil Nicholson of Cornell University, Ithaca, New York, co-authored the work with Hedman. "Appearances can be deceiving," said Nicholson. "A good analogy is how a foggy meadow is much more opaque than a swimming pool, even though the pool is denser and contains a lot more water."

Research on the mass of Saturn's rings has important implications for their age. A less-massive ring would evolve faster than a ring containing more material, becoming darkened by dust from meteorites and other cosmic sources more quickly. Thus, the less massive the B ring is, the younger it might be — perhaps a few hundred million years instead of a few billion.

"By 'weighing' the core of the B ring for the first time, this study makes a meaningful step in our quest to piece together the age and origin of Saturn's rings," said Linda Spilker, Cassini project scientist at NASA's Jet Propulsion Laboratory, Pasadena, California. "The rings are so magnificent and awe-inspiring, it's impossible for us to resist the mystery of how they came to be."

While all the giant planets in our solar system (Jupiter, Saturn, Uranus, and Neptune) have ring systems of their own, Saturn's are clearly different. Explaining why Saturn's rings are so bright and vast is an important challenge in understanding their formation and history. For scientists, the density of material packed into each section of the rings is a critical factor in ascribing their formation to a physical process.

An earlier study by members of Cassini's composite infrared spectrometer team had suggested the possibility that there might be less material in the B ring than researchers had thought. The new analysis is the first to directly measure the density of mass in the ring and demonstrate that this is the case. Hedman and Nicholson used a new technique to analyze data from a series of observations by Cassini's visible and infrared mapping spectrometer as it peered through the rings toward a bright star. By combining multiple observations, they were able to identify spiral density waves in the rings that aren't obvious in individual measurements.

The analysis also found that the overall mass of the B ring is unexpectedly low. It was surprising, said Hedman, because some parts of the B ring are up to 10 times more opaque than the neighboring A ring, but the B ring may weigh in at only 2 to 3 times the A ring's mass.

Despite the low mass found by Hedman and Nicholson, the B ring is still thought to contain the bulk of material in Saturn's ring system. And although this study leaves some uncertainty about the ring's mass, a more precise measurement of the total mass of Saturn's rings is on the way. Previously, Cassini

had measured Saturn's gravity field, telling scientists the total mass of Saturn and its rings. In 2017, Cassini will determine the mass of Saturn alone by flying just inside the rings during the final phase of its mission. The difference between the two measurements is expected to finally reveal the rings' true mass.

The study was published online by the journal *Icarus.* For more information, visit *http://saturn.jpl.nasa.gov.*

The Voyage of a Lifetime: New Horizons Marks 10 Years Since Launch

Ten years ago one of the great robotic explorers of our age — NASA's New Horizons spacecraft — rocketed into the sky above the Florida coastline. The tiny probe — weighing barely 453 kilograms (1000 pounds) — sped from Earth faster than any spacecraft before it, embarking on a 9.5-year voyage across more than 5 billion kilometers (3 billion miles) that culminated last summer in the historic first reconnaissance of Pluto and its family of small moons.

A composite of enhanced color images of Pluto (lower right) and Charon (upper left), taken by New Horizons as it passed through the Pluto system on July 14, 2015. Credit: JHU/APL.

"With that flyby New Horizons completed a long-held goal of the scientific community and also five-decade-long quest by NASA to explore all the planets known at the start of the space age," said New Horizons Principal Investigator Alan Stern, of the Southwest Research Institute, Boulder, Colorado. "And that all got its start 10 years ago with our launch."

Today, New Horizons, now far beyond Pluto, continues to send back data from that July 14 encounter, and the detailed views of these strange new worlds on the planetary frontier have amazed scientists and the public alike. The excitement of scientific discovery may have pushed the launch further back into collective memory, but the event that started New Horizons toward Pluto and the once-unexplored Kuiper belt still has special meaning to the team that designed, built, and then guided the spacecraft through the solar system.

Just 13 months later, New Horizons flew past Jupiter, getting a gravity assist that added another 14,484 kilometers per hour (9000 miles per hour) to its pace toward Pluto, and giving the team a chance to train the spacecraft's instruments on the giant planet and its largest moons. The Jupiter flyby was a mission in itself, helping the team gain flyby experience and producing discoveries that included the first close-up looks at lightning near Jupiter's poles and the first motion-picture sequence of an erupting volcano on the jovian moon Io.

The spacecraft began hibernating after the Jupiter flyby was complete, but mission activity barely slowed down from there. While New Horizons continued across the solar system at record speed, the science, spacecraft, and operations teams designed and practiced the intricate activities of the upcoming Pluto encounter. The spacecraft spent more than two-thirds of its seven-year cruise between Jupiter and Pluto in hibernation — which saved wear-and-tear on its systems and required fewer tracking resources at home.

"Mission Operations personnel always got the question, 'How are you going to keep busy and motivated for the 9½ years it's going to take to get to Pluto?'" said Mission Operations Manager Alice Bowman, of the Johns Hopkins University Applied Physics Laboratory (APL), Laurel, Maryland. "I don't know a single New Horizons operations person who was ever bored or unmotivated during the long cruise to the Pluto system. We have a small team, and there always seemed to be a technical challenge, a new moon [to include in the observation plans], or something else that kept us engaged. The time went by faster than expected."

Busy as they were, just as much was happening for the team outside of the major responsibility of moving New Horizons through space. "The 10-year launch anniversary to me is a time to reflect on how far we have come together as people," said Mission Operations Flight Control Lead Becca Sepan, of APL. "I don't think it's a stretch to say that every single member of our team, across the science, engineering, operations, and outreach disciplines, experienced at least one major life event in the time New Horizons has been in flight."

Sepan points out that she had been engaged for less than a month when New Horizons launched; she's now a married mother of two. Fellow flight controller Melissa Jones said her family "didn't exist" in January 2006; when the spacecraft flew by Pluto last July 14 she watched the festivities at APL with her husband and three children, ages 8, 6, and 4.

Others on the team have lost family members; gotten engaged, married, or divorced; had children and grandchildren; bought their first houses; earned graduate degrees; and encountered all the events and changes you'd expect over a decade. "While we were busy developing command sequences, planning science observations, testing on the simulator, we talked about these major life events and our daily happenings," Sepan said. "After 10 years of doing that together, it's hard not to feel like we have an extended family in the New Horizons team."

The Pluto encounter began in January 2015, with distant images of Pluto and Charon the team used mostly for navigation. As New Horizons sped closer and the Pluto system grew from a pair of tiny white dots into a dynamic, colorful system of worlds, the milestone that seemed so far away on that mild January day was becoming more and more real. And as New Horizons began delivering the data and close-ups of Pluto and Charon that have dazzled the world — and opened the door to a new realm of the solar system that is unlike anything seen before — the sense of anticipation that began at launch has given way to a sense of pride and accomplishment.

"Looking at the images of Pluto, it is truly an amazing feeling to know that you helped make that happen," said Mission Operations team member Sarah Hamilton, of APL. "When I reflect on the last 10 years it is the team that I think about. The success of this mission truly is a team effort and it's a privilege to be a part of it."

For more information, visit *http://pluto.jhuapl.edu.*

Voyager Mission Celebrates 30 Years Since Uranus

Humankind has visited Uranus only once, and that was 30 years ago. NASA's Voyager 2 spacecraft got its closest look at the mysterious, distant, gaseous planet on January 24, 1986. Voyager 2 sent back stunning images of the planet and its moons during the flyby, which allowed for about 5.5 hours of close study. The spacecraft got within 81,500 kilometers (50,600 miles) of Uranus during that time.

Arriving at Uranus in 1986, Voyager 2 observed a bluish orb with extremely subtle features. A haze layer hid most of the planet's cloud features from view. Credit: NASA/JPL-Caltech.

"We knew Uranus would be different because it's tipped on its side, and we expected surprises," said Ed Stone, project scientist for the Voyager mission, based at the California Institute of Technology, Pasadena. Stone has served as project scientist since 1972, continuing in that role today.

Uranus revealed itself to be the coldest planet known in our solar system, even though it's not the farthest from the Sun. This is because it has no internal heat source. Scientists determined that the atmosphere of Uranus is 85% hydrogen and 15% helium. There was also evidence of a boiling ocean about 800 kilometers (500 miles) below the cloud tops.

Scientists also found that Uranus has a magnetic field different from any they had ever encountered previously. At Mercury, Earth, Jupiter, and Saturn, the magnetic field is aligned approximately with the rotational axis. "Then we got to Uranus and saw that the poles were closer to the equator," Stone said. "Neptune turned out to be similar. The magnetic field was not quite centered with the center of the planet."

This surface magnetic field of Uranus was also stronger than that of Saturn. Data from Voyager 2 helped scientists determine that the magnetic tail of Uranus twists into a helix stretching 10 million kilometers (6 million miles) in the direction pointed away from the Sun. Understanding how planetary magnetic

fields interact with the Sun is a key part of NASA's goal to understand the very nature of space. Not only does studying the Sun-planet connection provide information useful for space travel, but it helps shed light on the origins of planets and their potential for harboring life.

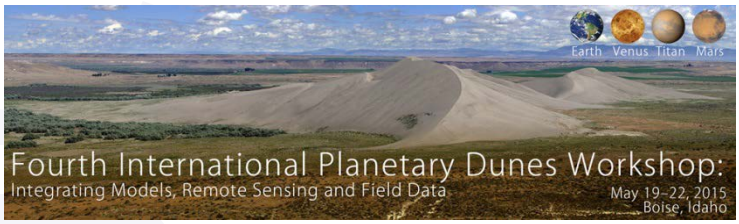
Voyager 2 also discovered 10 new moons (there are 27 total) and two new rings at the planet, which also proved fascinating. An icy moon called Miranda revealed a peculiar, varied landscape and evidence of active geologic activity in the past. While only about 500 kilometers (300 miles) in diameter, this small object boasts giant canyons that could be up to 12 times as deep as the Grand Canyon in Arizona. Miranda also has three unique features called "coronae," which are lightly cratered collections of ridges and valleys. Scientists think this moon could have been shattered and then reassembled.

Mission planners designed Voyager 2's Uranus encounter so that the spacecraft would receive a gravity assist to help it reach Neptune. In 1989, Voyager 2 added Neptune to its resume of first-ever looks. "The Uranus encounter was very exciting for me," said Suzanne Dodd, project manager for Voyager, based at NASA's Jet Propulsion Laboratory, Pasadena, California, who began her career with the mission while Voyager 2 was en route to Uranus." It was my first planetary encounter and it was of a planet humanity had never seen up close before. Every new image showed more details of Uranus, and it had lots of surprises for the scientists. I hope another spacecraft will be sent to explore Uranus, to explore the planet in more detail, in my lifetime."

Voyager 2 was launched on August 20, 1977, 16 days before its twin, Voyager 1. In August 2012, Voyager 1 made history as the first spacecraft to enter interstellar space, crossing the boundary encompassing our solar system's planets, Sun, and solar wind. Voyager 2 is also expected to reach interstellar space within the next several years. For more information, visit *http://www.nasa.gov/voyager* and *http://voyager.jpl.nasa.gov.*

Fourth International Planetary Dunes Workshop: Integrating Models, Remote Sensing and Field Data

May 19–22, 2015
Boise, Idaho



Aeolian bedforms have been observed across the solar system, from airless bodies that appear to have had at least transient atmospheres (e.g., comets) to places with extremely thick atmospheres (e.g., Venus). In order to advance our understanding of aeolian bedforms and processes across the solar system, 60 scientists and students representing 8 countries (from 4 continents) gathered in May 2015 in Boise, Idaho, to discuss remote sensing observations, laboratory experiments, *in situ* studies, and computer models of aeolian activity.

This workshop, the fourth in a series that focuses on planetary dunes, was convened as a means of bringing terrestrial and planetary researchers from diverse backgrounds together with the goal of fostering collaborative interdisciplinary research. The small-group setting facilitated intensive discussions of many aspects of aeolian processes on Earth, Mars, Venus, Titan, and even on comets.

The workshop produced a list of key scientific questions. Some of these questions related to specific processes:

- Under what, perhaps transient, conditions do aeolian bedforms develop on airless bodies?
- Under what planetary conditions do the Earth's oceans, lakes, and rivers provide suitable analogs to aeolian features observed on other worlds, e.g., Venus or Titan?
- How unique in morphology are the bedforms constructed by different processes and can the morphology of a bedform be used to discern the unique processes that formed it?

Scale was another common theme throughout the workshop. Comparative analysis of sand ripples, rectilinear ripples, megaripples, transverse aeolian ridges (TARs), and sand dunes on different planetary bodies suggest common processes that maintain similar bedforms over several orders of magnitude in size. Questions that arose regarding scale included:

- Are all measurable parameters scale-invariant?
- What spatial and temporal resolution is needed to evaluate scale variability?

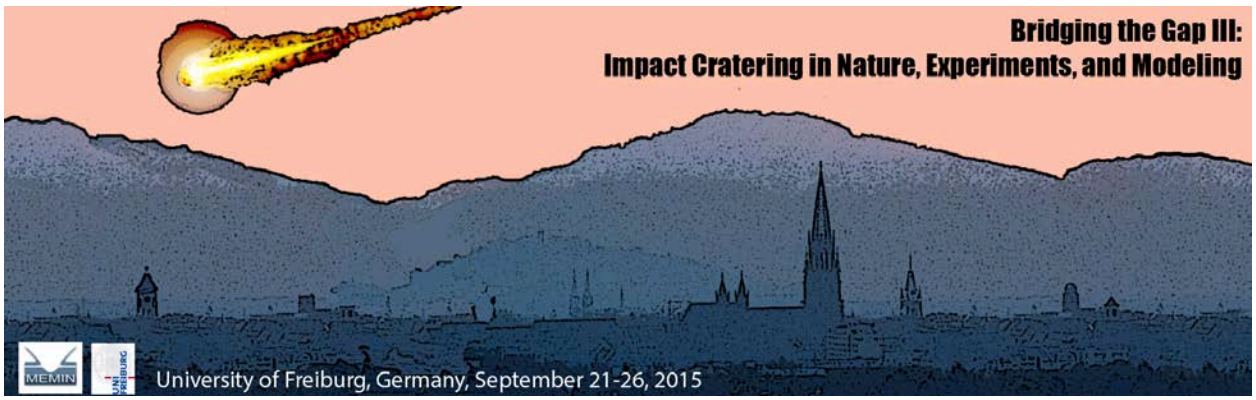
Many disciplines were represented at the workshop, enabling a comparison of the results of laboratory experiments, field experiments, modeling, and remote sensing observations. Comparisons benefit each

of these disciplines. For example, a comparison of modeling and field experiments may show that simple assumptions used in models do not fully describe observed aeolian processes, as when a single stress velocity threshold is insufficient to describe the mobility of actual sediment with a range of sizes and densities. Those from other disciplines often can contribute valuable insight into such discussions, and a more complete solution emerges.

More details about the workshop, including a link to the workshop report published in *Eos* in August 2015, are available at *http://www.hou.usra.edu/meetings/dunes2015/*.

Bridging the Gap III: Impact Cratering in Nature, Experiments, and Modeling

September 20–26, 2015
Freiburg, Germany



The process of impact cratering is a highly dynamic and complex phenomenon, and in order to understand the details of this process and further the state of knowledge, multi-disciplinary approaches are becoming more and more of a necessity for impact cratering research. The exchange between scientific results in modeling, experiments, field work, and remote sensing was the goal of the third "Bridging the Gap" conference, held at the foothills of the scenic Black Forest in Freiburg, Germany.

The conference continued the tradition of the two previous Bridging the Gap conferences held in 2003 at the Lunar and Planetary Institute in Houston, Texas, and in 2007 in Montreal, Canada. Thomas Kenkmann and Michael Poelchau (University of Freiburg), Stefan Hiermaier (Fraunhofer EMI, Freiburg), Alex Deutsch (University of Münster), and Fred Hörz (NASA JSC) invited researchers to Germany to participate in the week-long meeting. Nearly 120 scientists from 5 continents and 22 countries gathered together to discuss latest findings in the field of impact cratering and beyond.

Topics at the conference spanned the full spectrum of impact cratering, from shock-induced nanoscale phenomena to giant multi-ring impact basins over 1000 kilometers (621 miles) in diameter. A major topic of debate and controversy remains the genesis of suevite (a breccia with melt and shocked particles); fuel-coolant interaction between the impact melt and groundwater was discussed for the Nördlinger Ries, but observations from other craters suggest that different mechanisms may be necessary.

A good number of studies presented at the meeting showed how numerical models of impact cratering are being better constrained by the increasing amount of experimental, remote sensing, and ground truth data. For example, pre-impact particle location, ejection distances, and shock pressures from impact experiments into sand helped modelers to determine how important physical parameters like cohesion and porosity are for the excavation process. Similarly, the lunar Gravity Recovery and Interior Laboratory (GRAIL) gravity dataset or shock barometry measurements of quartz from drill cores of terrestrial craters yielded important constraints on crater-forming processes such as acoustic fluidization.

The inter- and multidisciplinary aspect of the conference was accentuated by several "excursions" that were offered alongside the presentations. Guided tours of the experimental facilities in the Fraunhofer EMI and University of Freiburg were given, showing participants the excitements and dangers of working in dynamic, experimental basement laboratories. A three-day field trip to the Nördlinger Ries and Steinheim craters was led by Thomas Kenkmann, forcing experimentalists and modelers to face the rain as well as the ground truth of field work in terrestrial impact craters, and discuss the intricacies of how these craters were formed. Numerical modelers repaid the favor by offering a novel session format to present the capabilities and limitations of numerical simulations to non-modelers. For the "virtual field trip," modelers set up several computer stations, each with a designated "pilot" as an expert in a specific modeling topic. Participants were then invited to wander between stations and view the models. This led to numerous fruitful discussions and was an eye opener for quite a number of researchers. There was an overwhelmingly positive response to the virtual field trip, and this concept will hopefully become a regular part of workshops and conferences of this size.

A further, pleasant surprise was the large and somewhat unexpected turnout of researchers interested in the conference. Nearly half of the participants were graduate and Ph.D. students, which we see as an important as well as promising sign for the future of the impact cratering research field.

For more information about the meeting, including links to the program and abstracts, visit *http://www.hou.usra.edu/meetings/gap2015/*.

SPICE Training Class Being Held in April

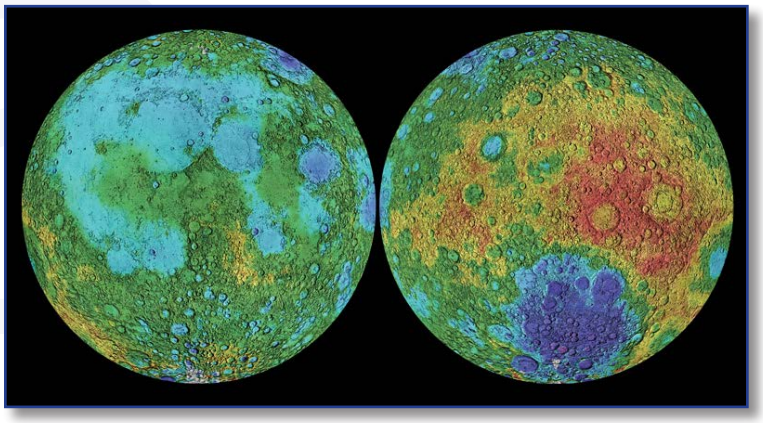
NASA's Navigation and Ancillary Information Facility (NAIF) at the Jet Propulsion Laboratory (JPL) announces a "SPICE" Training class to be held at the Double Tree by Hilton Hotel in Monrovia, California, on April 12–14, 2016. The class is free, but seating is limited, and seats will be allocated on a first-come, first-served basis contingent on the date of receipt of a completed registration form.

SPICE is an ancillary information system providing scientists and engineers access to spacecraft orbit, attitude, and similar information needed to determine observation geometry used in planning and analyzing space science observations. SPICE is frequently used for mission engineering functions as well. The SPICE system was conceived for and remains primarily focused on solar system exploration (planetary) missions, but has also proven useful for a variety of other purposes.

This class will be very similar to previous SPICE training sessions that have been offered, and should be considered a "beginner's" class. If you have taken a previous class, this one may not be very interesting unless you need a refresher on some of the basics of SPICE. The class is intended for those who will write software that will make use of SPICE data; those not intending to do programming using SPICE software may not find this class useful.

For more information about SPICE, visit *http://naif.jpl.nasa.gov/*. For more information about the training class, visit *http://naif.jpl.nasa.gov/naif/WS2016_announcement.html.*

Updated Edition of Lunar Impact Crater Database Now Available



The third edition of the Lunar Impact Crater Database, originally a Lunar and Planetary Institute (LPI) Lunar Exploration Intern Program project, is now available on the LPI website. Major revisions have been made, so those who have been using earlier editions of the database are encouraged to switch to the new edition.

The database can be accessed from two locations:

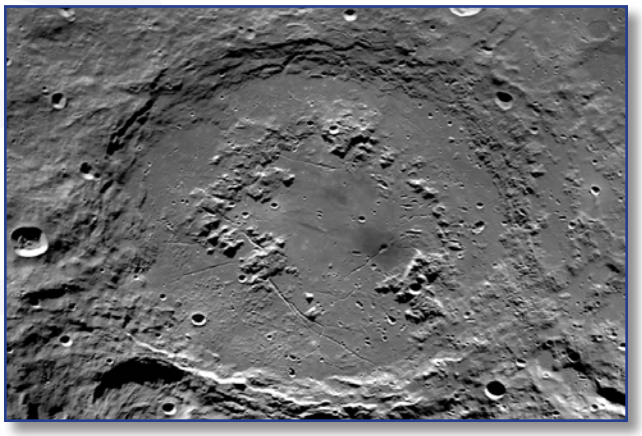
- From the "Impact Crater" subsection of the "Lunar Surface" section of the LPI Lunar Science and Exploration information portal (*http://www.lpi.usra.edu/lunar/surface/index.shtml#craters*)
- From LPI's list of scientific crater databases (*http://www.lpi.usra.edu/lpi/sci_database.shtml*)

The database is in Excel format, so it is very easy to sort and filter according to the user's needs.

The database has seen a number of major changes and additions of data since the second edition, which was released in 2011. The most important of these are:

- Crater coordinates and diameters are now taken from the official *IAU-USGS Working Group for Planetary System Nomenclature's Gazetteer of Planetary Nomenclature* (as of July 7, 2015). The previous editions of the database used data from *Andersson and Whitaker* (1982).
- In addition to the officially named craters (including the lettered satellite craters) and basins, the database now includes Apollo landing site craters because of their importance in lunar science and exploration. The total number of craters and basins in the database is now 8716.
- As before, the bulk of the database consists of various scaling laws compiled from literature, providing estimates of the craters' original properties. Some new scaling laws are provided, including melt volume scaling from *Abramov et al.* (2012) for 45° impacts on anorthosite and basalt. Radar halo diameters are now based on *Ghent et al.* (2010).
- The database now includes various spectroscopic properties of craters from a variety of sources.
- Other minor changes include a compilation of rayed craters and additional stratigraphic ages from USGS geologic maps. There are now 1675 craters with stratigraphic ages in the database.

CLSE Releases Video and Soundtrack of Schrödinger Basin



The lunar farside — that mysterious face of the Moon hidden from Earth — contains a cache of clues about how Earth formed, how planets evolved, and how volcanic and impact cratering processes reshaped the solar system. The farside of the Moon holds the key to the earliest bombardment of Earth and whether impact cratering processes were involved in the origin and earliest evolution of life on Earth.

The oldest and largest impact basin on the Moon is nearly 2500 kilometers (1553 miles) in diameter and stretches from the South Pole to a tiny crater called Aitken. This South Pole-Aitken (SPA) basin is one of the leading targets for human and

human-assisted robotic exploration. A particularly rich scientific and exploration target within that basin is the Schrödinger basin, about 320 kilometers (199 miles) in diameter, and located toward the south polar end of the SPA basin.

Scientists and engineers are already designing the methods for a mission to Schrödinger that collects samples and brings their extraordinary secrets back to Earth for study. To provide a perspective of this mission, the Center for Lunar Science and Exploration (CLSE) has created a video and soundtrack that carries viewers to the Moon, around the SPA basin, and to a first landing site within the Schrödinger basin. The new video illustrates the features that might be explored by a human-assisted sample-return mission to the Schrodinger basin. Hopefully this is the first step in an exhilarating mission of discovery.

The video is available at *http://www.lpi.usra.edu/exploration/SPA_Schrodinger1/*. The video can be played from within an Internet browser, but viewers who want the full experience can download the HD version and play it on their computers. A complete list of flyovers is available at *http://www.lpi.usra.edu/lunar/lunar_flyovers/*.

Tips for Processing LRO WAC Monochromatic Images with ISIS 3 for Photogeologic Purposes

The learning curve with the USGS Integrated Software for Imagers and Spectrometers (ISIS) can be pretty steep, particularly if you're not a geographic information systems (GIS)/image processing/Linux sort of a person, so Dr. Teemu Öhman of the Arctic Planetary Science Institute has written some brief instructions designed to make it a bit easier for beginners to produce Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC) images and mosaics that can be used for photogeologic analysis and various other purposes. The instructions assume that the user is familiar with ISIS and has succesfully installed it on their computer (which can sometimes be easier said than done).

The workflow includes photometric calibration utilizing Clementine calibration files. The resulting images are suitable for photogeologic research (but not spectro- or photometry). Batch processing scripts for LRO Narrow Angle Camera images are also included.

The instructions are available on the LPI website at *http://www.lpi.usra.edu/lunar/tools/dems/Ohman_mono-WAC_ISIS_procedure_v1-1.pdf*.

"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.

Lunar and Planetary Science Conference: Education Opportunities

The 47th Lunar and Planetary Science Conference will be held at The Woodlands Waterway Marriott Hotel and Convention Center, The Woodlands, Texas, March 21–25, 2016. There will be a variety of events and opportunities that will be of interest to the science education community and scientists who are involved in — or are interested in — education and public engagement. For more information, visit *http://www.hou.usra.edu/meetings/lpsc2016*.

Participate in E/PO Poster Sessions

Tuesday, March 22, 6:00 to 9:00 p.m., Town Center Exhibit Hall

There will be several E/PO poster sessions on the evening of Tuesday, March 22, covering such topics as digital and virtual education resources and experiences, engaging the STEM pipeline in mission and instrument design, engaging our audiences, and improving our practices. All conference attendees are invited to join us to discuss our efforts!

Educator Professional Development Workshop: Solar System Exploration

Sunday, March 20, 9:00 a.m. to 4:30 p.m., Waterway Ballrooms 7/8

Come learn about the latest discoveries on Pluto, ongoing research and new plans for Mars exploration, and how our missions are helping us understand how our solar system formed and evolved! Planetary scientists will be presenting overviews of the current research, and planetary education specialists will lead activities in the topic of solar system exploration. This workshop is geared for science teachers, professors, and informal science educators interested in knowing more about planetary science. Registration is free but required at *http://www.lpi.usra.edu/education/workshops/solar_system/registration*. For more information, contact Christine Shupla at *shupla@lpi.usra.edu*.

Early Career Presenters Review

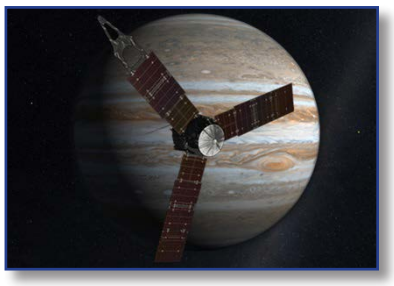
Sunday, March 20, 1:00 to 5:00 p.m., Panther Creek

Join other young scientists preparing to present their research at this educational opportunity to get feedback from seasoned presenters. Registration is required and limited to 20 presenters. Registration is available at *https://www.surveymonkey.com/r/Y6K3FP7*. Seasoned presenters wishing to participate as reviewers should contact Andy Shaner directly at *shaner@lpi.usra.edu*.

Upcoming Public Event Opportunities

Upcoming opportunities exist for educator and public engagement around the broader topics of NASA planetary exploration. Resources for evening observing session events include the Night Sky Network's Discover the Universe Guides at *https://nightsky.jpl.nasa.gov/news-display.cfm?News_ID=611* and the Lunar and Planetary Institute's *Look Up* guides at *http://www.lpi.usra.edu/education/look_up/*. Consider getting in touch with local astronomical societies, planetariums and museums, local scientists, and NASA's Solar System Ambassadors (*http://solarsystem.nasa.gov/ssa/directory.cfm*) — ask them to join your events and share their experiences or resources with the children.

Juno Arrives at Jupiter



The Juno mission will improve our understanding of the solar system's beginnings by revealing the origin and evolution of Jupiter. It is scheduled to begin orbiting Jupiter around July 4, 2016.

Audiences will be invited to act as a virtual imaging team, participating in key steps to process images from the JunoCam (*http://www.missionjuno.swri.edu/junocam*). Now and throughout the mission, amateur astronomers are invited to submit images of Jupiter from their own telescopes.

Other resources that can be used for your Juno events include Explore Jupiter's Family Secrets (*http://www.lpi.usra.edu/education/explore/solar_system/activities*), a module of activities showcasing how the Juno mission will unveil Jupiter's deepest secrets, including clues about how our solar system formed and Jupiter's unique traits.

OSIRIS-REx Launches

NASA's OSIRIS-REx Mission (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) will travel to near-Earth asteroid Bennu and bring a small sample back to Earth for study. OSIRIS-REx is scheduled to launch in September 2016.

All audiences are invited to submit artwork that will fly on the spacecraft; the submission deadline is March 20, 2016. For details, visit *http://www.asteroidmission.org/WeTheExplorers*.

Total Eclipse of the Sun

On August 21, 2017, there will be a total eclipse of the Sun visible from the U.S. The path of the total eclipse is only about 60 miles wide and goes from a beach in Oregon to a beach in South Carolina. The partial eclipse will be visible to 500 million people in the other parts of the U.S. and North America. Details are available at *http://sunearthday.nasa.gov/discoveries/science/2017-eclipse.php*.

The National Science Teachers Association (NSTA) is making available a popular-level introduction for students and the public to help explain the eclipse and how to view it: *http://www.nsta.org/publications/press/extras/files/solarscience/SolarScienceInsert.pdf*.

Field Training and Research Program at Meteor Crater

LPI-JSC's Center for Lunar Science and Exploration will conduct a student field camp opportunity September 3–11, 2016. The Field Training and Research Program at Meteor Crater is a week-long geology field class and research project based at Barringer Meteorite Crater, Arizona, more popularly known as Meteor Crater. The goal will be to introduce students to impact-cratering processes and provide an opportunity to assist with a research project at the crater. Skills developed during the field camp should better prepare the students for their own thesis studies in impact cratered terrains, whether they be on Earth, the Moon, asteroids, Mars, or some other solar system planetary surface.

The field camp is designed for graduate college students in geology and planetary science programs, although advanced undergraduate students will be considered if they have successfully completed a summer field geology program and have a demonstrated interest in impact cratering processes. U.S. and international students are eligible to apply. The application deadline is June 13, 2016. For more information and access to an electronic application form, please visit *http://www.lpi.usra.edu/exploration/mcFieldCamp*.

Barringer Grant Applications for 2016

Graduate students and postdocs are invited to apply for grants from the Barringer Family Fund for Meteorite Impact Research; the application deadline is April 8, 2016. This program provides three to five competitive grants each year in the range of $2500 to $5000 for support of field research at known or suspected impact sites worldwide. Grant funds may be used to assist with travel and subsistence costs, as well as laboratory and computer analysis of research samples and findings. Masters, doctoral, and post-doctoral students enrolled in formal university programs are eligible. Over the past 14 years, 51 research projects have been supported. For additional details and an application form, visit *http://www.lpi.usra.edu/science/kring/Awards/Barringer_Fund*.

GEOPATH: Inclusive Field-Based Geoscience Undergraduate Research Opportunities

James Madison University is leading an accessible geoscience field studies program offering opportunities for students with various mobile abilities to collaborate in an inclusive field-based environment, regardless of physical ability. In the first year, students will participate in an end-of-semester active research project at exciting geological field sites, including the Grand Canyon, the Barringer Meteorite Crater, and the San Francisco Volcanic Field. In year 2017, students will participate fully, regardless of mobility, in an accessible expedition to multiple sites in western Ireland. All participants will receive a $1000 stipend for each of the two years of the project, along with travel funds to all the field sites. Learn more and apply to participate at *http://www.theiagd.org/geopath*.

Mildred Shapley Matthews, 1915–2016

On February 11, just four days short of her 101st birthday, Mildred Shapley Matthews passed away peacefully at her home in California with her family present. Matthews was the daughter of Harvard College Observatory Director Harlow Shapley, and she held the interesting distinction of being "lost in the solar system" for 75 years. As a commemoration of his newborn daughter, Shapley bestowed the name "Mildred" to asteroid 878 discovered in 1916. Unfortunately, the initial observations of the asteroid were limited, and the object was "lost" with highly uncertain orbital elements until recovered in 1991. Friends and colleagues seeing Matthews over the years would always ask, "Are you found yet?"

Matthews' foundational contributions to planetary science began around the time of her nominal retirement age, when in the 1970s she began working as the production editor in the inaugural years of the Space Science Series created by Tom Gehrels. Her role became most prominently recognized as co-editor on more than a dozen volumes extending into the 1990s. Ultimately, for the more than 20 Space Science Series volumes she edited, operating through friendly (then increasingly stern, but always polite) postcards and phone calls to delinquent authors, it was Matthews who brought the books into their final published form. Matthews leaves behind a legacy of books that have served as the gateway for countless planetary science careers and insights toward future advancements in our field. In 1993, Matthews received the DPS' Harold Masursky Award for Meritorious Service to Planetary Science.

— Text courtesy of Richard P. Binzel and the Division of Planetary Sciences

Wolfgang Elston, 1928–2016

Wolfgang Elston died peacefully at his home in Albuquerque, New Mexico, on February 29, 2016.

Elston was born August 13, 1928, and in 1939 the family fled Nazi Germany. His parents settled in New York City, but the start of World War II prevented Elston and his brother Gerhard from leaving England, where they lived from 1939 to 1945. After immigrating to the U.S. in 1945, Elston received a degree in geology from the City College of New York and a Ph.D. in geology from Columbia University. His thesis research brought him to southwestern New Mexico in 1950, mapping for the State of New Mexico.

After serving in the U.S. Army and spending two years teaching geology at Texas Tech University, Elston moved to Albuquerque in 1957, where he began a nearly 60-year career teaching geology at the University of New Mexico (UNM).

Elston's research interests were wide ranging, teaching and conducting research in mining geology and volcanology. He was a pioneer in planetary geology, and was happiest when doing field research, traveling to field sites as distant as New Zealand, Australia, and southern Africa, where he did extensive work on the Bushveld Complex. During his tenure at UNM he mentored many students, many of whom went on to become geology professors and researchers, and he continued advising students following his formal retirement from UNM in 1993.

Grateful to the U.S. for his citizenship, he donated time and money to the cause of refugees, and lectured on the Holocaust and the evils of intolerance to adults and schoolchildren. In addition to his professional contributions to the field of geology, he will long be remembered for his wit, generosity, sense of humor, and humanitarian efforts.

— Portions of text courtesy of the Albuquerque Journal

Schmelz Named as One of *Nature*'s Top Ten

Joan Schmelz, Deputy Director of the Arecibo Observatory in Puerto Rico, was named by *Nature* magazine in late December as one of the "Ten People Who Mattered This Year." *Nature* cited Schmelz's behind-the-scenes work exposing the issue of sexual harassment in the astronomy work place, an issue Schmelz fought hard to bring to light during her tenure as chair of the American Astronomical Society's Committee on the Status of Women in Astronomy.

For more information about Schmelz's accomplishments, as well information about the other honorees, read the full article at *http://www.nature.com/news/365-days-nature-s-10-1.19018*.

Mackwell Has Asteroid Named After Him

Stephen J. Mackwell, Director of the Lunar and Planetary Institute (LPI) in Houston, Texas, has been honored by the International Astronomical Union (IAU) with the naming of main-belt asteroid (5292) Mackwell (formerly designated as 1991 AJ_1). It is a fitting honor for Mackwell, who is a valued steward of the science community, known for his studies of the deformation of rocks and minerals at high-temperature and high-pressure conditions, relevant to the lithospheres and interiors of the terrestrial planets.

Hitoshi Shiozawa and Minoru Kizawa originally discovered asteroid (5292) Mackwell on January 12, 1991, in Fujieda, Shizuoka Prefecture, Japan. (5292) Mackwell has an absolute magnitude of 11.9, and is part of the main asteroid belt, which is located between the orbits of planets Mars and Jupiter.

Mackwell performs research into the dynamics of the lithospheres and interiors of the terrestrial planets through experimental studies of the deformation of rocks and minerals at high-temperature and pressure conditions. Such studies have focused on the mechanical behavior of rocks of basaltic composition, as well as upper mantle rocks and minerals. Particular attention has been paid to the role of chemical environment, notably the water and oxygen partial pressures. Weakening effects due to textural evolution during high-strain deformation have also been studied.

Mackwell also investigates the role of chemical environment on diffusion within minerals and on kinetics of mineral reactions. In particular, he has focused on the rates of water uptake and loss from minerals in

mantle xenoliths during transport from the mantle source region, with implications for the water content of Earth's interior. His work on mineral reactions during high-temperature experiments has enabled calculation of grain boundary diffusion rates in polymineralic aggregates, with implications for phase transition kinetics and rheological behavior.

Before coming to the LPI in 2002, Mackwell was Director of the Bayerisches Geoinstitut in Bayreuth, Germany. He has been the recipient of numerous honors, including Fellow of the American Geophysical Union; Stipendiat der Alexander von Humboldt-Stiftung, Bayreuth, Germany; Ministère de L'Education Nationale, Academie de Lille, Nommé Professeur; and Fellow of the Mineralogical Society of America. He has also served on the editorial board of numerous prestigious planetary science journals, including serving as editor-in-chief for *Geophysical Research Letters* from 2002 to 2004.

JPL Director Charles Elachi Receives Awards

Charles Elachi, director of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, is being honored with a pair of prestigious awards: the 2016 Aviation Week Laureate Award for Lifetime Achievement, and the National Space Trophy from the Rotary National Award for Space Achievement Foundation.

The Laureate Award, which was presented March 3 at the National Building Museum in Washington, recognizes the "extraordinary achievements of individuals and teams in aviation, aerospace and defense. Their accomplishments embody the spirit of exploration, innovation and vision that inspire others to strive for progress, change and leadership in aviation and aerospace." Elachi was chosen for "guiding an amazing period of solar system exploration by robotic spacecraft and generating public enthusiasm for space science during his 45-year career." That lengthy career at JPL has included 15 years as director.

"Aerospace, and in particular, space exploration, have made tremendous strides during the past few decades. I'm honored, as part of the JPL team and more recently as the JPL director, to have played a role in the important stories of exploration that inspire the public," Elachi said.

On April 29, Elachi will receive the National Space Trophy from the Rotary National Award for Space Achievement Foundation, during a banquet to be held at the Houston Hyatt Regency. The trophy is presented each year to "an outstanding American who has made major contributions to our nation's space program." The foundation's Board of Advisors includes NASA center directors; aerospace corporation presidents; military, news media, academic and political leaders; and previous trophy winners.

The former director of NASA's Goddard Space Flight Center in Greenbelt, Maryland, A. Thomas Young, nominated Elachi. "Charles Elachi's distinguished leadership and sustained technical achievement

have had a profound impact on the U.S. robotic exploration of space across the late 20th and early 21st centuries," said Young. "His contributions and vision have impacted space science and technology, generations of young people and professionals, and society at large."

Upon learning he was to receive the trophy, Elachi said, "I feel so fortunate to be involved in space exploration during an extremely exciting time, when we are rewriting science books, fulfilling humanity's innate quest for discovery, and bringing tangible technology and science advances back to Earth. I am grateful for the invaluable contributions of the teams of dedicated and immensely talented men and women I've worked with through the years."

On June 30 of this year, Elachi will retire from his post at JPL, but will continue as professor emeritus at the California Institute of Technology (Caltech) in Pasadena. He is already serving as a Caltech vice president and professor of electrical engineering and planetary science. During Elachi's 15 years as director, JPL has seen more than 25 successful missions, including Mars Curiosity, the Mars Phoenix lander, the rovers Spirit and Opportunity, the GRAIL lunar mission, Mars Reconnaissance Orbiter, Dawn, Spitzer Space Telescope, NuSTAR, the Jason series, GRACE, Deep Impact, Genesis, and the ongoing explorations of the Cassini and Voyager missions.

Spudis to Receive Columbia Medal

Paul D. Spudis, a Senior Staff Scientist at the Lunar and Planetary Institute (LPI) in Houston, Texas, is the recipient of the 2016 Columbia Medal for his contributions that advance aerospace engineering.

Spudis was selected by the Aerospace Division of the American Society of Civil Engineers for his outstanding service as a geologist specializing in the terrestrial planets, with extensive background in geology and planetary science, including interpretation of remote-sensing and image data and integrated studies with information from planetary samples. The award presentation will take place during the Earth and Space Conference Engineering for Extreme Environments in Orlando, Florida, on April 14, 2016.

Spudis' research focuses on the processes of impact and volcanism on the planets and studies of the requirements for a sustainable human presence on the Moon. He has served as Deputy Leader of the Science Team for the Department of Defense's Clementine mission to the Moon in 1994, Principal Investigator of the Mini-SAR imaging radar experiment on India's Chandrayaan-1 mission in 2008–2009, and team member for the Mini-RF imaging radar on NASA's Lunar Reconnaissance Orbiter mission (2009–present).

Spudis has also served as a member of the White House Synthesis Group in 1990–1991 and on the President's Commission on the Implementation of U. S. Space Exploration Policy in 2004, and was presented with the NASA Distinguished Public Service Medal that same year. He is the recipient of numerous awards, including the 2006 Von Karman Lectureship in Astronautics, awarded by the American Institute for Aeronautics and Astronautics; a 2011 Space Pioneer Award from the National Space Society; and the 2014 Eugene M. Shoemaker Distinguished Lunar Scientist Award, presented by the NASA Solar System Exploration Research Virtual Institute (SSERVI).

Spudis is the author or co-author of over 115 scientific papers and seven books, including *The Once and Future Moon,* a book for the general public in the Smithsonian Library of the Solar System series; *The Clementine Atlas of the Moon,* published by Cambridge University Press; and the forthcoming *The Value of the Moon: How to Explore, Live and Prosper in Space Using the Moon's Resources*, to be published in April 2016 by Smithsonian Books.

Mars Landing Pioneer Elected to National Academy of Engineering

Adam Steltzner, a JPL engineer who helped pioneer the breakthrough technique for landing a one-ton rover on Mars, is being honored with admission into the National Academy of Engineering. Steltzner is recognized for development of the Mars Curiosity rover's entry, descent, and landing system and for contributions to control of parachute dynamics. Election to the academy is among the highest professional distinctions for an engineer. Academy membership honors those who have made outstanding contributions to "engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature" and to "the pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education."

Steltzner has worked on multiple NASA flight projects, including Galileo, Cassini, Mars Pathfinder, and the Mars Exploration Rovers (Spirit and Opportunity). The earlier rovers — Pathfinder's Sojourner, as well as Spirit and Opportunity — landed on Mars with the help of specially designed airbags. NASA's next Mars rover, Curiosity, was so much heavier it needed a different design for entry, descent, and landing. Steltzner was involved in the design and led the team that developed the entry, descent, and landing system, which included the innovative sky crane landing system that placed Curiosity on Mars in August 2012. The technology will also be used to land the Mars 2020 rover. Steltzner is currently serving as chief engineer for the Mars 2020 Project, and is also manager of the Planetary Entry, Descent and Landing and Small Body Access Office.

The newly elected class will be formally inducted during a ceremony at the academy's annual meeting in Washington on October 9.

NASA Scientists, Engineers Receive Presidential Early Career Awards

In February, President Obama named six NASA researchers as recipients of the 2016 Presidential Early Career Award for Scientists and Engineers (PECASE). These recipients, and 100 other federal researchers, will receive their awards in a ceremony later this year in Washington.

The PECASE awards represent the highest honor bestowed by the U.S. government on scientists and engineers who are beginning their research careers. The award recognizes recipients' exceptional potential for leadership at the frontiers of scientific knowledge, as well as their commitment to community service as demonstrated through professional leadership, education or community outreach.

"These early career scientists and engineers represent some of the best and brightest talent in our agency and our university partners," said NASA Administrator Charles Bolden. "We are delighted to see them win this prestigious award, as their contributions will benefit our nation and advance the scientific frontiers."

The following 2016 NASA recipients were nominated by the agency's Science Mission Directorate, and its Offices of the Chief Engineer and Chief Technologist: Dr. James Benardini, planetary protection (NASA's Jet Propulsion Laboratory in Pasadena, California); Dr. Jin-Woo Han, nanodevices and nanoelectronics (NASA's Ames Research Center in Moffett Field, California); Dr. Michele Manuel, self-healing metals (University of Florida, Gainesville); Dr. Andrew Molthan, cloud microphysics (NASA's Marshall Space Flight Center in Huntsville, Alabama); Dr. Colleen Mouw, oceanography and public health (Michigan Technological University, Houghton); and Dr. Vikram Shyam, technical innovation in fundamental aeronautics (NASA's Glenn Research Center in Cleveland).

The PECASE awards were created to foster innovative developments in science and technology, increase awareness of careers in science and engineering, give recognition to the scientific missions of participating agencies, enhance connections between fundamental research and many of the grand challenges facing the nation, and highlight the importance of science and technology for America's future.

Todd May Named Marshall Space Flight Center Director

NASA Administrator Charles Bolden has named Todd May director of the agency's Marshall Space Flight Center in Huntsville, Alabama. May was appointed Marshall deputy director in August 2015 and has been serving as acting director since the November 13, 2015, retirement of Patrick Scheuermann. As director, May will lead one of NASA's largest field installations, with almost 6000 civil service and contractor employees, an annual budget of approximately $2.5 billion, and a broad spectrum of human spaceflight, science, and technology development missions.

"Todd's experience and leadership have been invaluable to the agency, especially as we have embarked on designing, building, and testing the Space Launch System, a critical part of NASA's journey to Mars," said Bolden. "He brings his expert program management and leadership skills and sense of mission to this new role, and I look forward to having him at the helm of Marshall."

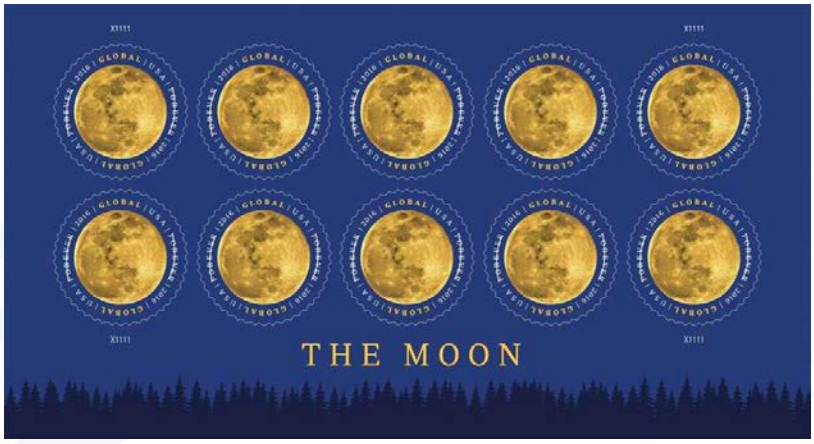
Since its inception in 2011, May led the Space Launch System (SLS) program through a series of milestones, including a successful in-depth critical design review. SLS, now under development, is the most powerful rocket ever built, able to carry astronauts in NASA's Orion spacecraft on deep space missions, including to an asteroid and ultimately on a journey to Mars.

May's NASA career began in 1991 in the Materials and Processes Laboratory at Marshall. He was deputy program manager of the Russian Integration Office in the International Space Station Program at NASA's Johnson Space Center in Houston in 1994. May managed the successful integration, launch and commissioning of the station's Quest airlock in 1998. He also joined the team that launched the Gravity Probe B mission to test Einstein's general theory of relativity.

In 2004, May assumed management of the Discovery and New Frontiers Programs, created to explore the solar system with frequent unmanned spacecraft missions. He moved to NASA Headquarters in Washington in 2007 as a deputy associate administrator in the Science Mission Directorate. Returning to Marshall in June 2008, May was named Marshall's associate director, technical, a post he held until being named SLS program manager.

May earned a bachelor's degree in materials engineering from Auburn University in Auburn, Alabama, in 1990. His many awards include NASA's Exceptional Achievement Medal, the Presidential Rank Award of Meritorious Executive, NASA's Outstanding Leadership Medal and the John W. Hager Award for professionalism in materials engineering. He has been named a Distinguished Engineer by Auburn. In 2014, he received Aviation Week's Program Excellence Award, as well as the Rotary National Award for Space Achievement Foundation's Stellar Award in recognition of the SLS team's many accomplishments.

U.S. Postal Service Releases *The Moon* Forever Stamp



On February 22 the U.S. Postal Service released a new, one-ounce, international-rate stamp, *The Moon* Forever®. Issued at the price of $1.20, this Global Forever stamp can be used to mail a one-ounce letter to any country to which U.S. First-Class Mail International service is available. As with all Global Forever stamps, this stamp will have a postage value equivalent to the price of a single-piece First-Class Mail International one-ounce machinable letter in effect at the time of use. To distinguish this stamp from other Forever stamps, the shape of the international stamp is round and bears the words "Global Forever." *The Moon* features a detailed photograph of the full Moon, capturing the brilliant surface of Earth's only natural satellite.

The Moon is a fitting choice for a Global Forever commemorative stamp, because exploration of the Moon has always been an international endeavor. Even though the Apollo program was led by the U.S., analyses of its valuable lunar samples involved scientists from around the world from the first day samples were returned to Houston. The spirit of that international endeavor has continued over the past half century, during which a growing number of nations have reached lunar orbit and landed on the lunar surface.

There is a growing realization that the Moon is the best and most accessible place to explore the origin and evolution of the solar system. As capabilities — such as NASA's Orion crew vehicle, its Space Launch System, and ESA's Orion service module — are being constructed for flights beyond low-Earth orbit, mission concepts that utilize those capabilities are being developed.

In support of the multi-agency International Space Exploration Coordination Group, which has been pursuing a Global Exploration Roadmap, human-assisted robotic sample return missions are being studied. One of those concepts, called HERACLES, could return to Earth exciting new samples that test fundamentally important concepts, such as an early globally-magmatic phase for Earth and the Moon and a subsequent period of severe asteroid and comet bombardment that completely resurfaced Earth and the Moon immediately prior to our earliest evidence of life on Earth. An international group of students recently helped design two potential traverses for the rover in the HERACLES mission concept and will be presenting those results at the upcoming international Lunar and Planetary Science Conference in March. The Moon remains a guiding light for space exploration.

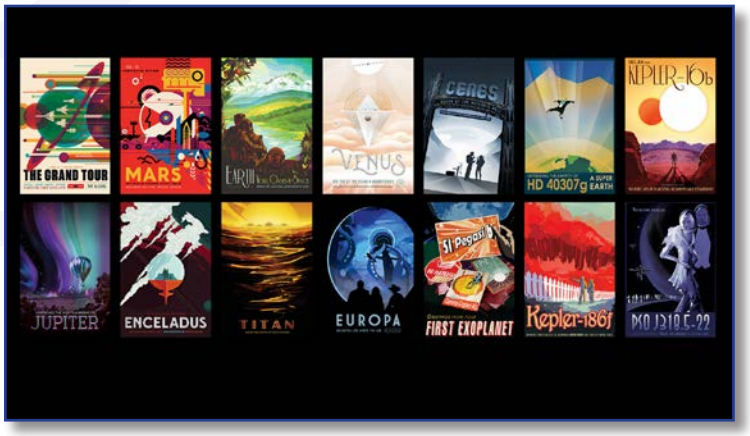
ESA Moon Challenge 2015

The finale of the "ESA Moon Challenge 2015" took place during the recent International Symposium on Moon 2020–2030, held in December at Noordwijk, The Netherland. The European Space Agency (ESA) program invited students from around the world to design lunar mission concepts that were compatible with the Human-Enhanced Robotic Architecture and Capabilities for Lunar Exploration and Science (HERACLES) study for an ESA-led mission that aims to be the next step in lunar exploration.

The HERACLES architecture framework defines a series of end-to-end missions to the lunar surface, and serves both as inspiration for, and as a set of primary constraints for, the teams. In addition to a conceptual study of the architecture, teams submitted simulations illustrating their planned operational activities on the lunar surface and its vicinity. University students from around the world competed as part of the symposium, and the challenge attracted 234 students from 108 universities in 38 countries. One of the main objectives was to examine human-robotic partnerships — the interaction between crew and automated systems considered to be a promising aspect of future space exploration missions.

ESA astronaut Jean-Francois Clervoy distributed the final awards to the top three designs. The winning submissions are being assessed by ESA for their utility in possible future studies of mission scenarios. To view a spectacular video featuring footage of 22 different simulations submitted by the teams, visit *http://www.esa.int/spaceinvideos/Videos/2015/12/ESA_Moon_Challenge_2015*.

Exotic Cosmic Locales Available as Space Tourism Posters

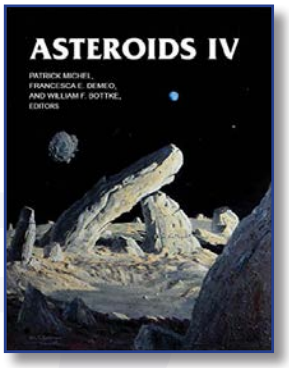


Imagination is our window into the future. New travel posters from NASA's Jet Propulsion Laboratory envision a day when the creativity of scientists and engineers will allow us to do things we can only dream of now. You can take a virtual trip to 14 alien worlds, and maybe even plaster your living room with planetary art, via the new, futuristic space tourism posters. The posters are available free for downloading and printing at *http://www.jpl.nasa.gov/visions-of-the-future*.

Last year, five posters depicting planets beyond our solar system were introduced as part of JPL's Exoplanet Travel Bureau series. They are included in the latest set of 14 posters, which also show such locales as Mars, Jupiter's moon Europa, Saturn's vapor-spewing moon Enceladus, and the dwarf planet Ceres. The posters are the brainchild of The Studio at JPL, a design and strategy team that works with JPL scientists and engineers to visualize and depict complex science and technology topics. Their work is used in designing space missions and in sharing the work of NASA/JPL with the public.

Note: Product descriptions are taken from the publisher's website. LPI is not responsible for factual content.

BOOKS



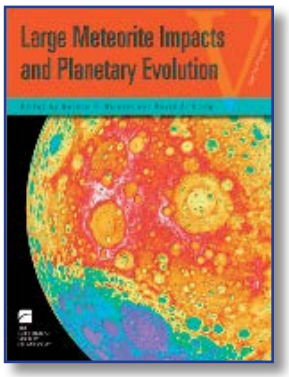
Asteroids IV.

Edited by Patrick Michel, Francesca E. Demeo, and William F. Bottke. University of Arizona Press. 2015, 758 pp., Hardcover, $75.00. *www.uapress.arizona.edu*

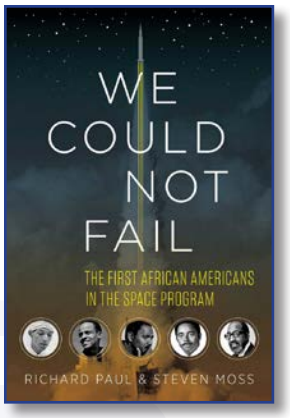
Over the past decade, asteroids have come to the forefront of planetary science. Scientists across broad disciplines are increasingly recognizing that understanding asteroids is essential to discerning the basic processes of planetary formation, including how their current distribution bespeaks our solar system's cataclysmic past. For explorers, the nearest asteroids beckon as the most accessible milestones in interplanetary space, offering spaceflight destinations easier to reach than the lunar surface. For futurists, the prospects of asteroids as commercial resources tantalize as a twenty-first-century gold rush, albeit with far greater challenges than faced by nineteenth-century pioneers. For humanity, it is the realization that asteroids matter. It is not a question of if — but when — the next major impact will occur. While the disaster probabilities are thankfully small, fully cataloging and characterizing the potentially hazardous asteroid population remains unfinished business. *Asteroids IV* sets the latest scientific foundation upon which all these topics and more will be built upon for the future. Nearly 150 international authorities through more than 40 chapters convey the definitive state of the field by detailing our current astronomical, compositional, geological, and geophysical knowledge of asteroids, as well as their unique physical processes and interrelationships with comets and meteorites. Most importantly, this volume outlines the outstanding questions that will focus and drive researchers and students of all ages toward new advances in the coming decade and beyond.

Large Meteorite Impacts and Planetary Evolution V.

Edited by Gordon R. Osinski and David A. Kring. Geological Society of America. 2015, 227 pp., Paperback. $60.00. *rock.geosociety.org/store*



Impact cratering is one of the most fundamental geological processes. On many planets, impact craters are the dominant geological landform. On Earth, erosion, plate tectonics, and volcanic resurfacing continually destroy the impact cratering record, but even here, the geological, biological, and environmental effects of impact cratering are apparent. Impact events are destructive and have been linked to at least one of the "big five" mass extinctions over the past 540 million years. Intriguingly, impact craters can also have beneficial effects. Many impact craters are associated with economic metalliferous ore deposits and hydrocarbon reservoirs. This special paper provides an up-to-date synthesis of impact cratering processes; the role of meteorite impacts in the origin of life, products, and effects; and the techniques used to study impact craters on Earth and other planetary bodies. This volume resulted from the Large Meteorite Impacts and Planetary Evolution V conference held in Sudbury, Canada, in August 2013.



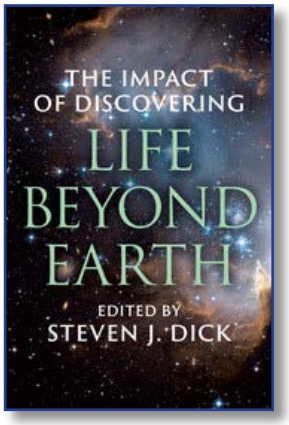
We Could Not Fail: The First African Americans in the Space Program.

By Richard Paul and Steven Moss. University of Texas Press, 2015, 312 pp., Hardcover, $30.00. *utpress.utexas.edu*

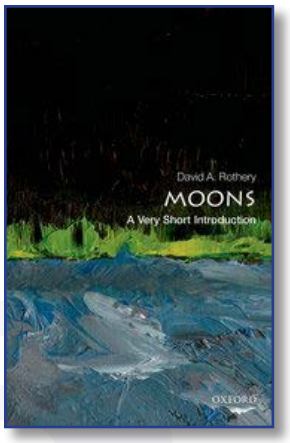
The Space Age began just as the struggle for civil rights forced Americans to confront the long and bitter legacy of slavery, discrimination, and violence against African Americans. Presidents John F. Kennedy and Lyndon B. Johnson utilized the space program as an agent for social change, using federal equal employment opportunity laws to open workplaces at NASA and with NASA contractors to African Americans while creating thousands of research and technology jobs in the Deep South to ameliorate poverty. *We Could Not Fail* tells the inspiring, largely unknown story of how shooting for the stars helped to overcome segregation on Earth. The authors profile 10 pioneering African American space workers whose stories illustrate the role NASA and the space program played in promoting civil rights. They recount how these technicians, mathematicians, engineers, and an astronaut candidate surmounted barriers to move, in some cases literally, from the cotton fields to the launching pad. The authors vividly describe what it was like to be the sole African American in a NASA work group and how these brave and determined men also helped to transform Southern society by integrating colleges, patenting new inventions, holding elective office, and reviving and governing defunct towns. Adding new names to the roster of civil rights heroes and a new chapter to the story of space exploration, *We Could Not Fail* demonstrates how African Americans broke the color barrier by competing successfully at the highest level of American intellectual and technological achievement.

The Impact of Discovering Life Beyond Earth.

Edited by Steven J. Dick. Cambridge University Press, 2015, 366 pp., Hardcover, $29.99. *www.cambridge.org*



The search for life in the universe, once the domain of science fiction, is now a robust research program with a well-defined roadmap, from studying the extremes of life on Earth to exploring the possible niches for life in the solar system and discovering thousands of planets far beyond it. In addition to constituting a major scientific endeavor, astrobiology is one of the most popular topics in astronomy, and is of growing interest to a broad community of thinkers from across the academic spectrum. In this volume, distinguished philosophers, theologians, anthropologists, historians, and scientists discuss the big questions about how the discovery of extraterrestrial life, whether intelligent or microbial, would impact society. Their remarkable and often surprising findings challenge our foundational concepts of what the discovery of alien life may hold for humankind. Written in easily accessible language, this thought-provoking collection engages a wide audience of readers from all backgrounds.



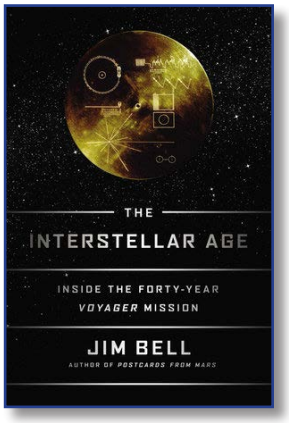
Moons: A Very Short Introduction.

By David Rothery. Oxford University Press, 2016, 144 pp., Paperback, $11.95. *global.oup.com*

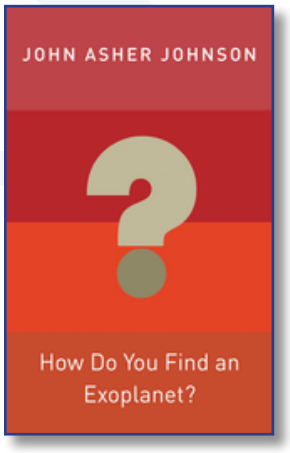
This book, part of the bestselling *Very Short Introductions* series, introduces the reader to the moons of our solar system, including their discovery and naming; explains the nature and influence of our Moon; and provides an up-to-date account detailing what we know about the nature and formation of other planets' moons based on data gathered by Voyager, Galileo, and other spacecraft.

The Interstellar Age: Inside the Forty-Year Voyager Mission.

By Jim Bell. Dutton, 2015, 336 pp., Hardcover, $27.95. *www.penguin.com*



The Voyager spacecraft are our farthest-flung emissaries — 11.3 billion miles away from the crew who built and still operate them, decades since their launch. Voyager 1 left the solar system in 2012; its sister craft, Voyager 2, left in 2015. The fantastic journey began in 1977, before the first episode of *Cosmos* aired. The mission was planned as a grand tour beyond our Moon; beyond Mars, Jupiter, and Saturn; and maybe even into interstellar space. The fact that it actually happened makes this humanity's greatest space mission. Award-winning planetary scientist Jim Bell reveals what drove and continues to drive the members of this extraordinary team, including Ed Stone, Voyager's chief scientist and the one-time head of NASA's Jet Propulsion Laboratory; Charley Kohlhase, an orbital dynamics engineer who helped to design many of the critical slingshot maneuvers around planets that enabled the Voyagers to travel so far; and the geologist whose Earth-bound experience would prove of little help in interpreting the strange new landscapes revealed in the Voyagers' astoundingly clear images of moons and planets. Speeding through space at a mind-bending eleven miles per second, Voyager 1 is now beyond our solar system's planets. It carries with it artifacts of human civilization. By the time Voyager passes its first star in about 40,000 years, the gold record on the spacecraft, containing various music and images including Chuck Berry's "Johnny B. Goode," will still be playable.



How Do You Find an Exoplanet?

By John Asher Johnson. Princeton University Press, 2016, 200 pp., Hardcover, $35.00. *press.princeton.edu*

Alien worlds have long been a staple of science fiction. But today, thanks to modern astronomical instrumentation and the achievements of many enterprising observational astronomers, the existence of planets outside our solar system — also known as exoplanets — has moved into the realm of science fact. This book is an authoritative primer on the four key techniques that today's planet hunters use to detect the feeble signals of planets orbiting distant stars. The author provides the reader with an insider's perspective on

this exciting cutting-edge science, showing how astronomers detect the wobble of stars caused by the gravitational tug of an orbiting planet, the slight diminution of light caused by a planet eclipsing its star, and the bending of space-time by stars and their planets, and how astronomers even directly take pictures of planets next to their bright central stars. Accessible to anyone with a basic foundation in college-level physics, this book sheds new light on the prospect of finding life outside our solar system, how surprising new observations suggest that we may not fully understand how planets form, and much more.

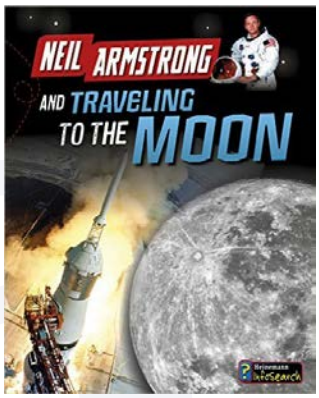
DVD

The Martian.

Produced by 20th Century Fox, 2015, one disk. $29.98. *www.foxconnect.com*

Matt Damon leads a stellar cast in this breathtaking sci-fi adventure from legendary director Ridley Scott (*Alien, Prometheus*) based on the #1 New York Times best-selling novel. During a manned mission to Mars, American astronaut Mark Watney (Damon) is presumed dead and left behind by his crew. But Watney is still alive, and he must now find a way to contact Earth — and survive on a barren planet with meager supplies — in the hope that an international team of scientists can devise a near-impossible rescue plan to bring him home!

FOR KIDS!!!



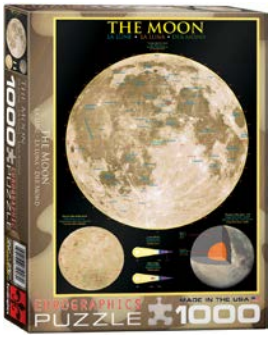
Neil Armstrong and Traveling to the Moon.

By Ben Hubbard. Heinemann-Raintree, 2015, 48 pp., Paperback. $8.99. *www.capstonepub.com*

Join Neil Armstrong on his journey to the Moon! This book examines the extraordinary life of the first astronaut to set foot on the Moon, from his early life to his first trip onboard an American spacecraft. Discover what the space race was, and other developments that were happening at the time. Find out about the rigorous training that astronauts undergo and how they prepare for a journey into the unknown. For ages 9 to 11.

The Moon 1000-Piece Jigsaw Puzzle.

Produced by Eurographics Puzzles. $19.99. *www.eurographicspuzzles.com*



This high-quality jigsaw puzzle shows various perspectives of the Moon such as the nearside, farside, and sliced images of the surface. This superior-quality puzzle, made from recycled board and printed with vegetable-based ink, will delight and educate at the same time. The puzzle's finished size is 19.25" × 26.5". For ages 6 and up.

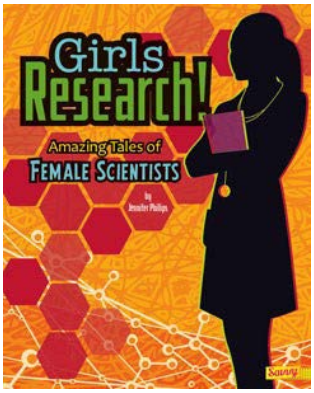
GeoSafari® Talking Planetary Mat.

Produced by Educational Insights. $54.99.
www.educationalinsights.com

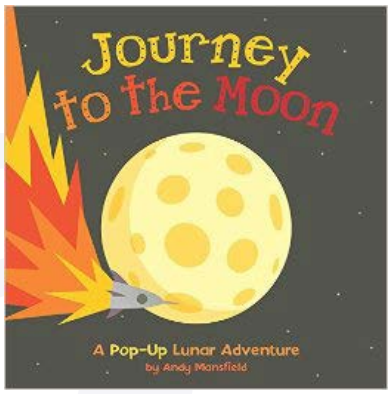
Did you ever wonder how much you'd weigh on the Moon? Jupiter? Mars? Step onto the Talking Planetary Mat and find out! A completely interactive way to demonstrate the changing forces of gravity on the different planets, this mat features all eight planets and our Moon, as well as fun, recorded facts to help kids understand gravity, weight, mass, and basic astronomy. The mat includes a galactic planet scale printed with nine celestial bodies and can calculate a child's weight on all eight planets and the Moon in both pounds and kilos. It will reinforce planetary knowledge with more than 40 fun facts. The mat measures 42" around and has an 8.5" × 11" scale. For ages 6 to 12.

Girls Research! Amazing Tales of Female Scientists.

By Jennifer Phillips. Capstone Press, 2015, 64 pp., Hardcover, $33.99.
www.capstonepub.com



Never before have so many awesome women been celebrated in one book. The scientists featured in this book broke barriers, made life-changing discoveries, and forever transformed the world. Their words change us. Their power amazes us. Their talent awes us. And their stories inspire us all. For grades 4 to 5.



Journey to the Moon: A Pop-Up Lunar Adventure.

By Andy Mansfield. Little Bee Books, 2015, 14 pp., Hardcover, $12.99.
www.littlebeebooks.com

Take an out-of-this-world journey to the Moon in this exciting book filled with pop-up scenes. If you go to the Moon, there is a surprise in store — but half the fun is getting there. In this beautifully crafted popup book, count down to blast off in a rocket ship, then zoom through space and prepare for landing. But you're not an astronaut . . . you're an alien going home to visit your mom! For ages 4 to 8.

Calendar 2016

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

April

4–8 **International Venus Conference 2016,** Oxford, United Kingdom. *http://venus2016.uk/*

8 **Royal Astronomical Society Meeting on Space Resources,** Burlington House, Piccadilly, London. *https://www.ras.org.uk/component/gem/?id=375*

11–15 **15th Biennial ASCE International Conference in Engineering, Science, Construction and Operations in Challenging Environments,** Orlando, Florida. *http://earthspaceconf.mst.edu/*

21–22 **The Asteroid-Meteorite Connection,** Los Angeles, California. *http://planets.ucla.edu/meetings/upcoming-meetings/amcw2016/*

25–28 **From Star and Planet Formation to Early Life,** Vilnius, Lithuania. *http://www.vilnius2016.eu*

May

16–19 **Biosignature Preservation and Detection in Mars Analog Environments,** Lake Tahoe, Nevada. *http://www.hou.usra.edu/meetings/biosignature2016/*

17–19 **Humans to Mars Summit,** Washington, DC. *http://h2m.exploremars.org*

17–19 **International Workshop About Comets in Honor of Hans Rickman,** Paris, France. *https://indico.obspm.fr/event/9/*

18–19 **4th European Lunar Symposium, Trippenhuis (Dutch Royal Academy of Arts and Sciences),** Amsterdam, The Netherlands. *http://sservi.nasa.gov/els2016/*

22–26 **Japan Geoscience Union Meeting,** Chiba, Japan. *http://www.jpgu.org/meeting_e2016/index.htm*

24–25 **5th Interplanetary CubeSat Workshop,** Oxford, United Kingdom. *http://icubesat.org/*

24–26 **New Views of the Moon 2,** Houston, Texas. *http://www.hou.usra.edu/meetings/newviews2016/*

27–30 **Fourth Beijing Earth and Planetary Interior Symposium,** Beijing, China. *http://bepis2016.csp.escience.cn*

29–Jun 24 **Water in the Solar System and Beyond,** Rome, Italy. *http://www.vaticanobservatory.va/content/specolavaticana/en/summer-schools--voss-/voss2016.html*

June

1–3 **2nd Asteroid Impact Deflection Assessment (AIDA) International Workshop 2016,** Nice, France. *https://www-n.oca.eu/michel/AIDAWorkshop2016/*

2–4 **Next-Generation Suborbital Researchers Conference,** Broomfield, Colorado. *http://nsrc.swri.org*

7–9 **7th Joint Meeting of The Space Resources Roundtable (SRR) and the Planetary and Terrestrial Mining Sciences Symposium (PTMSS),** Golden, Colorado. *http://www.cmspace.com/events/srr*

9–10 **3rd International Symposium on Lunar and Planetary Science,** Wuhan, China. *http://www.must.edu.mo/ISLPS2016/*

11–12 **International Planetary Probe Short Course,** Laurel, Maryland. *http://ippw2016.jhuapl.edu/*

13–15 **2016 Annual Laboratory Astrophysics Division of the AAS Meeting,** San Diego, California. *http://lad.aas.org/meetings/lad2016*

13–17 **International Planetary Probe Workshop (IPPW-13),** Laurel, Maryland. *http://ippw2016.jhuapl.edu/*

14–15 **Cometary Science After Rosetta,** London, United Kingdom. *https://royalsociety.org/events/2016/06/cometary-science/*

16–17 **Cometary Science After Rosetta: Future Directions,** London, United Kingdom. *http://www.ucl.ac.uk/mssl/planetary-science/comets-after-rosetta*

20–21 **Martian Gullies and Their Earth Analogues,** London, England. *http://www.geolsoc.org.uk/martiangullies*

21–23 **Binaries in the Solar System IV,** Prague, Czech Republic. *http://www.boulder.swri.edu/binaries4-mtg/*

26–Jul 1 **26th Goldschmidt Conference,** Yokomama, Japan. *http://goldschmidt.info/2016/*

26–Jul 1 **Extrasolar Planets: Their Formation and Evolution,** Bad Honnef, Germany. *http:/www.tat.physik.uni-tuebingen.de/~kley/exo16/*

27–29 **Titan Aeronomy and Climate Workshop,** Reims, France. *http://planeto.univ-reims.fr/tac/*

28–30 **15th Meeting of the NASA Small Bodies Assessment Group (SBAG),** Washington, DC. *http://www.lpi.usra.edu/sbag/*

July

3–8 **Exoplanets Conference,** Davos, Switzerland. *http://www.exoplanetscience.org/*

3–8 **International Symposium and Workshop on Astrochemistry,** Campinas, Brazil. *http://www1.univap.br/gaa/iswa/*

10–12 **Astrobiology Australasia Meeting 2016,** Perth, Australia. *http://www.aa-meeting2016.com*

11–15 **New Directions in Planet Formation,** Leiden, The Netherlands. *https://www.lorentzcenter.nl/lc/web/2016/799/info.php3?wsid=799&venue=Oort*

11–15 **4th International HSE Geochemistry Workshop,** Durham, United Kingdom. *http://www.hseworkshop.co.uk/*

20–22 **NASA Exploration Science Forum,** Moffett Field, California. *http://nesf2016.arc.nasa.gov/index*

22–24 **Dusty Visions Workshop,** Boulder, Colorado. *http://impact.colorado.edu/DustyVisions2016*

24–28 **2016 Microscopy and Microanalysis Conference,** Columbus, Ohio. *http://www.microscopy.org/MandM/2016/*

25–29 **NASA Planetary Science Summer School,** Pasadena, California. *https://pscischool.jpl.nasa.gov/index.cfm*

25–29 **2016 Sagan Exoplanet Summer Workshop,** Pasadena, California. *http://nexsci.caltech.edu/workshop/index.shtml*

26–29 **Enceladus and the Icy Moons of Saturn,** Boulder, Colorado. *http://www.hou.usra.edu/meetings/enceladus2016/*

30–Aug 7 **41st Scientific Assembly of the Committee on Space Research (COSPAR 2016),** Istanbul, Turkey. *http://www.cospar-assembly.org*

August

1–4 **The Diversity of Planetary Atmospheres (IV),** Squamish, Canada. *http://www.exoclimes.org*

7–12 **79th Meeting of the Meteoritical Society,** Berlin, Germany. *http://www.metsoc-berlin.de/*

15–19 **The 9th Meeting on Cosmic Dust,** Sendai, Japan. *http://www.cps-jp.org/~dust/Welcome.html*

23–Sep 11 **Summer School "Volcanism, Plate Tectonics, Hydrothermal Vents and Life," Angra Do Heroísmo,** Azores, Portugal. *http://www.nordicastrobiology.net/Azores2016*

27–Sep 4 **35th International Geological Congress,** Cape Town, South Africa. *http://www.35igc.org/*

September

5–9 **6th International Conference on Mars Polar Science and Exploration,** Reykjavik, Iceland. *http://www.hou.usra.edu/meetings/marspolar2016/*

12–14 **Linking Exoplanet and Disk Compositions,** Baltimore, Maryland. *http://www.cvent.com/d/ffqwn1*

October

17–21 **IAU Symposium 328: Living Around Active Stars,** Baresias, Brazil. *http://www.iau.org/science/meetings/future/symposia/1161/*

24–26 **Global Congress and Expo on Materials Science and Nanoscience,** Dubai, UAE. *http://scientificfederation.com/materialsscience-congress/*

24–27 **3rd International Workshop on Instrumentation for Planetary Missions,** Pasadena, California. *http://www.hou.usra.edu/meetings/ipm2016/*

November

14–18 **Comets 2016,** Toulouse, France. *http://www.comets2016toulouse.com*

15–17 **14th Meeting of the Venus Exploration Analysis Group (VEXAG),** Location to be announced. *http://www.lpi.usra.edu/vexag/*

December

12–16 **2016 AGU Fall Meeting,** San Francisco, California. *http://agu.org*

January 2017

11–13 **Dust, Atmosphere, and Plasma Environment of the Moon and Small Bodies (DAP 2017),** Boulder, Colorado. *http://impact.colorado.edu/dap_meeting.html*