NASA'S MARS SCIENCE LABORATORY CURIOSITY ROVER MISSION: Studying Ancient, Habitable Environments in Gale Crater

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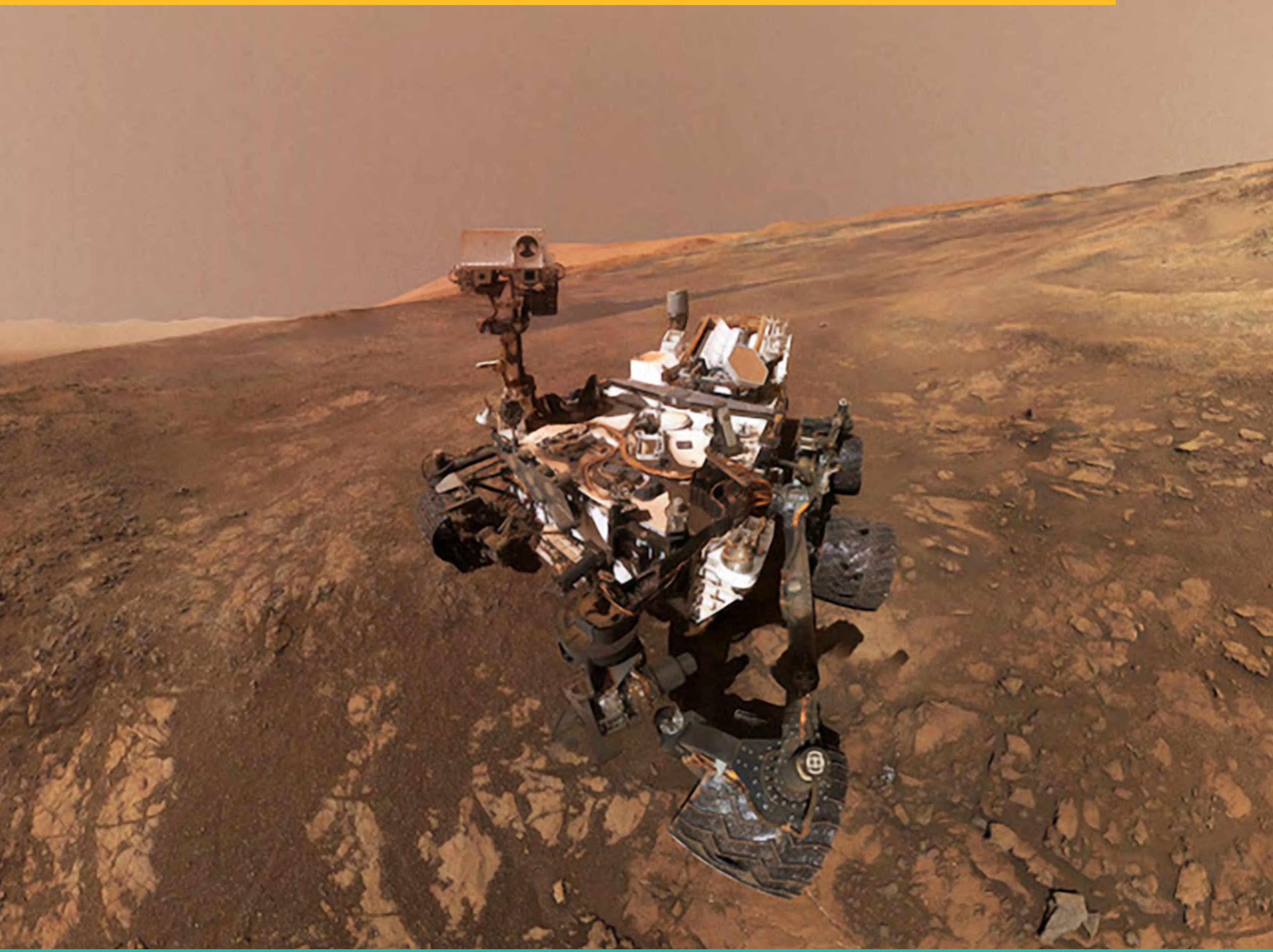

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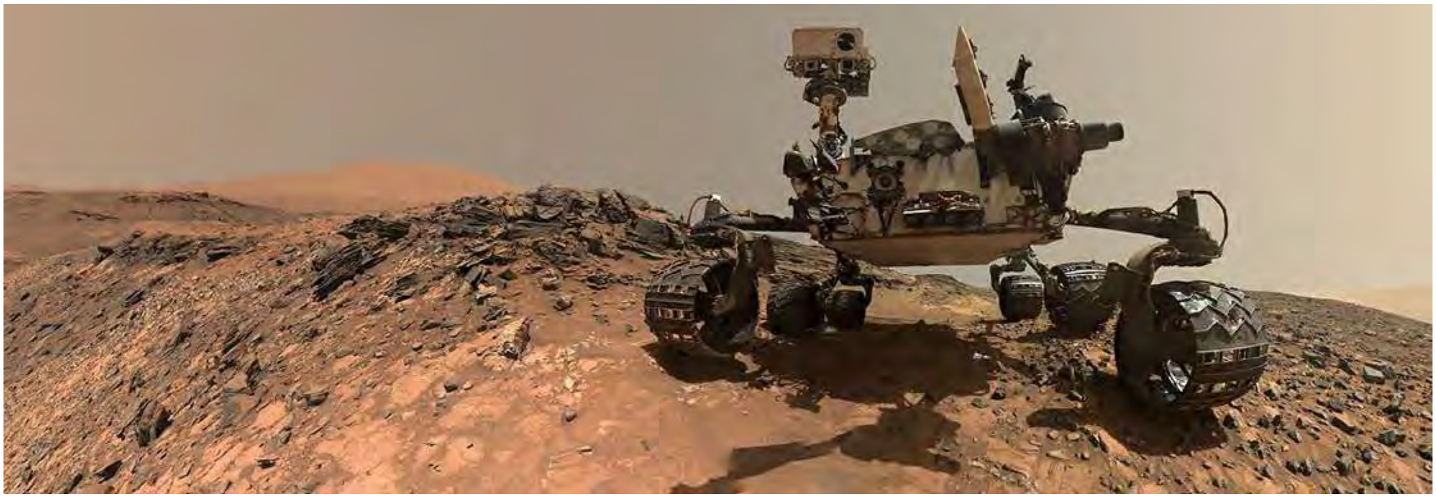
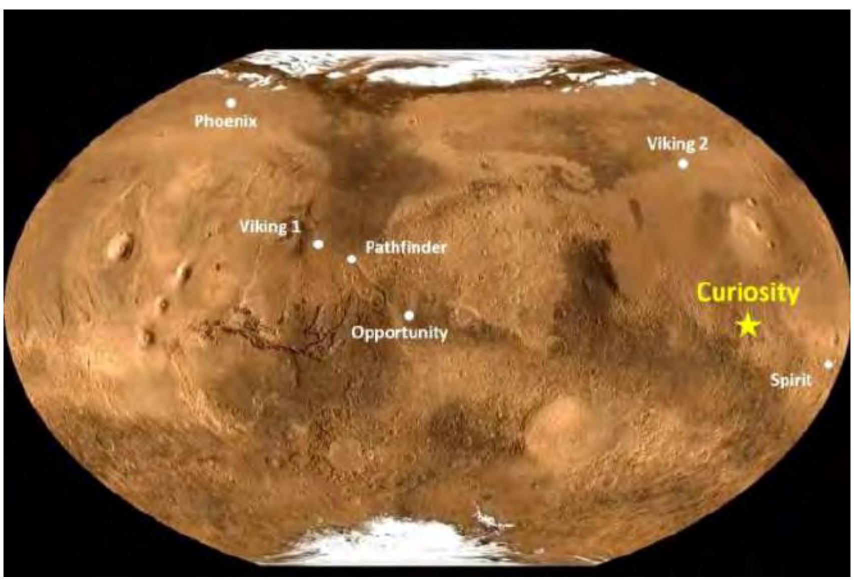
Feature Story



NASA's Mars Science Laboratory Curiosity Rover Mission: Studying Ancient, Habitable Environments in Gale Crater

Robotic Exploration of Mars Before Curiosity

The Mars Science Laboratory (MSL) Curiosity rover continues a legacy of exploration of the martian surface and atmosphere from orbiting and landed robotic missions. The first flyby of Mars was completed by the Mariner 4 mission in 1965, with two more flybys by Mariners 6 and 7 in 1969. The images of the martian surface transmitted by these flybys showed a desolate, cratered terrain, much like the lunar surface, which was likely a disappointing result for those who hypothesized that Mars was much more Earth-like and had liquid water and active volcanos on its surface. The orbiting spacecraft Mariner 9 mapped ~80% of the martian surface in the early 1970s and found evidence of an intriguing geologic history, with ancient river channels, huge extinct volcanos (the largest of which is the size of the state of Arizona), volcanic and impact craters, and a canyon system that is over 3000 kilometers long. Although the martian surface does not currently look very Earth-like, the images from Mariner 9 suggested that Mars may have once looked very much like Earth. This led people to wonder if microbial life could have ever existed on the planet, and the search for life and environments that would have been habitable to microbial life on Mars began.



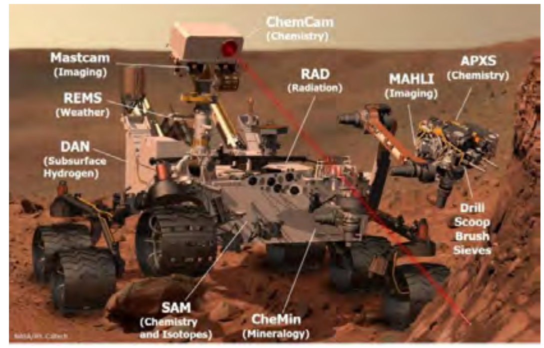
Landing sites for previous Mars rovers and landers and for Curiosity. Credit: NASA/JPL-Caltech.

Following the Mariner missions, the NASA Viking 1 and 2 missions launched for Mars in 1975. Each mission included an orbiter and a lander. The goals of the landers were to image the martian surface and look for evidence for life using biological experiments. The experiments produced no definitive evidence for life at either landing site. Orbiters with high-resolution cameras and infrared spectrometers (for identifying minerals on the surface) were launched in the late 1990s and early 2000s, including the NASA Mars Global Surveyor (launched in 1997), the NASA Mars Odyssey (2001), the European Space Agency (ESA) Mars Express (2003), and the NASA Mars Reconnaissance Orbiter (2006). High-resolution cameras [in particular the High Resolution Imaging Science Experiment (HiRISE) on Mars Reconnaissance Orbiter, which can collect images with a resolution of ~30 centimeters/pixel] have returned stunning images of ancient river channels and lake deposits in impact craters that are 3–4 billion years old. *[NOTE: Ages for terrestrial planet surfaces are estimated by counting the number and size of impact craters. This method is based on the premise that a new geologic surface (like a lava flow or landslide deposit) would have zero impact craters, and as the surface ages, meteorites hit the surface and the surface accumulates craters. The ages have been calibrated by samples returned from the Moon, whose ages have been determined from radiometric age dating.]* Orbiters dedicated to studying the atmosphere have been launched recently, including NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) mission (2013) and ESA's ExoMars Trace Gas Orbiter (2016).

Infrared spectrometers on Mars Global Surveyor, Mars Odyssey, Mars Express, and Mars Reconnaissance Orbiter have shed light on the minerals on the martian surface. Minerals are important because they can tell us about the history of a surface, from igneous processes like the composition of magmas and lavas, to processes involving water like the formation and evolution of lakes and the chemistry of those lake waters. Some minerals discovered in sedimentary rocks deposited ~3–4 billion years ago (Ga) indicate that ancient aqueous environments were diverse and evolved during

Mars' early history. Minerals from the phyllosilicate group (also called clay minerals) are common in very ancient terrains (~3.5–4 Ga), whereas sulfate salts are more common in slightly younger terrains (~3–3.5 Ga). Phyllosilicates require liquid water to form and can form under a range of conditions, but the most common phyllosilicates found on the martian surface (called smectite) suggest formation under near-neutral pH and relatively low temperatures (between ~0° and 100°C). Sulfate salts are found in drier environments where waters containing SO_4^{2-} in solution have evaporated such that sulfate-bearing salts precipitated. This observation of phyllosilicates in the most ancient terrains and sulfate salts in slightly younger terrains suggests that surface water chemistry on Mars changed ~3.5 Ga, marking a global climate change from a relatively wet early Mars to the very dry Mars we know today.

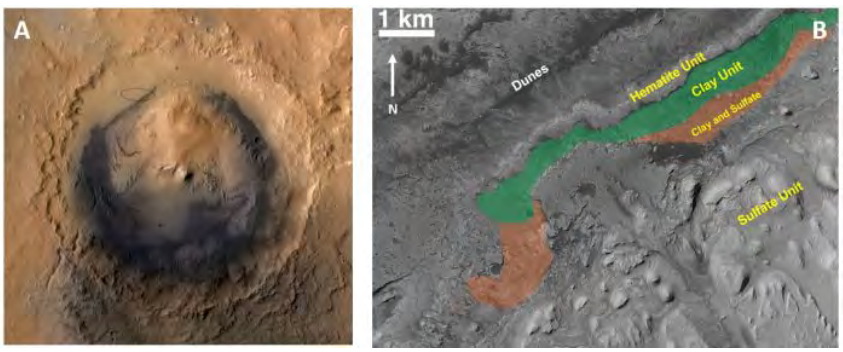
NASA's Mars Pathfinder Sojourner (1996) was the first rover sent to Mars and it found rocks deposited by water in a massive ancient outflow channel called Ares Vallis. The twin NASA Mars Exploration Rovers Spirit and Opportunity (2003) were each sent to sites on Mars with evidence for liquid water from orbit, and both rovers found geochemical evidence for a variety of different aqueous environments. The NASA Phoenix lander (2007) landed in the northern plains of Mars to study the biological potential of the martian arctic soils with cameras, a trench-digging robotic arm, and wet chemistry laboratories. Phoenix discovered water ice in the near subsurface, and the chemistry measurements showed the soil was slightly alkaline with modest salinity, but that liquid water had likely not been present for hundreds of millions of years. Curiosity continues this search for habitable environments on the martian surface with a sophisticated science payload.



Curiosity's science instruments. Credit: NASA/JPL-Caltech.

Curiosity Mission Goals, Instruments, and the Selection of Gale Crater

A main scientific goal of the Curiosity mission is to assess the habitability of ancient martian environments. Habitable environments are defined as those that would support microbial life. Life as we know it on Earth requires liquid water and specific nutrients. The science instruments on the Curiosity rover can look for evidence for ancient liquid water based on geologic context, the types of minerals present, and geochemistry and can detect elements and nutrients necessary for life.



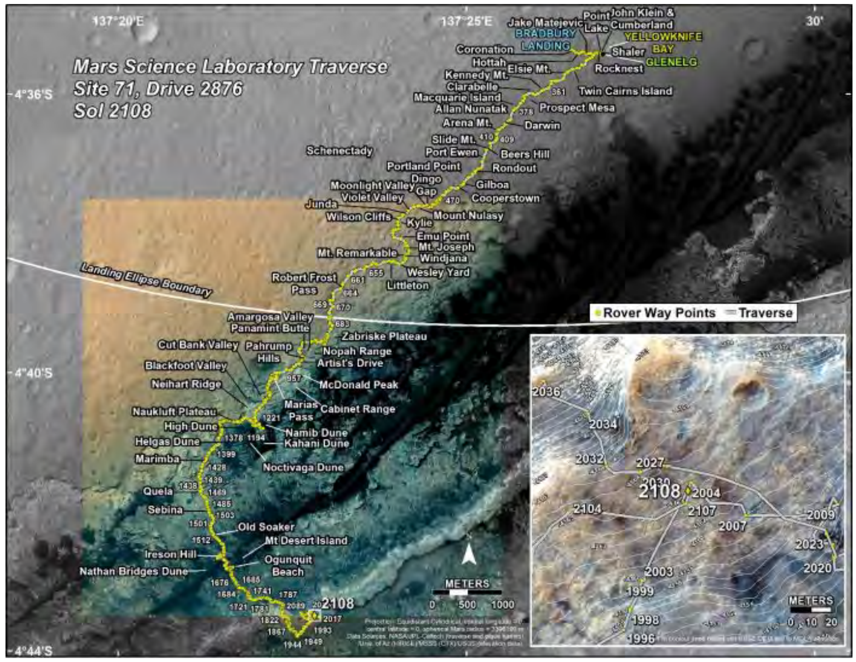
(a) Composite image of Gale crater with the landing ellipse in black in the northwestern crater plains. Credit: NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS. (b) HiRISE image of the lower slopes of Mount Sharp with mineral units highlighted. Credit: NASA/JPL-Caltech/MSSS.

The science cameras include Mastcam, the Mars Hand Lens Imager (MAHLI), and the Remote Micro Imager (RMI) on the Chemistry and Camera (ChemCam) instrument package. Mastcam is made up of two cameras of different focal lengths on the mast of the rover and provides stunning outcrop-to horizon-scale images. The ChemCam RMI generally produces context images of rock and soil targets that the ChemCam Laser Induced Breakdown Spectrometer (LIBS) instrument analyzes for geochemistry, but can also image features that are hundreds of meters to a few kilometers away from the rover. MAHLI produces close-up images of rocks and soils and can resolve features as small as ~12.5 micrometers.

The instruments used for characterizing composition of rocks and soils (i.e., geochemistry and mineralogy) are the ChemCam LIBS instrument, the Alpha Particle X-ray Spectrometer (APXS), the Chemistry and Mineralogy instrument (CheMin), the Sample Analysis at Mars (SAM) instrument package, and the Dynamic Albedo of Neutrons (DAN) instrument. ChemCam and Mastcam also perform spectroscopy in the visible and near-infrared wavelengths, which can be used to identify certain minerals, in particular those that contain iron. ChemCam is located on the mast of the rover and the LIBS instrument fires a laser up to 7 meters away, which creates a plasma out of the target soil or rock. A spectrometer then measures the plasma to determine the chemical composition of the target. The APXS is located on the end of the arm and measures the bulk geochemistry of soil and rock targets up close. CheMin and SAM are laboratories located on the inside of the rover and they both analyze scooped soil and drilled rock samples that are acquired and processed with the Sample Acquisition, Processing, and Handling (SA/SPaH) subsystem on the end of the arm. CheMin can quantify the minerals present in soils and rocks down to a detection limit of ~1 wt.%. SAM is a suite of three instruments (a mass spectrometer, gas chromatograph, and tunable laser spectrometer) that measure gases that are released from soil and rock samples as they are heated to search for carbon-, nitrogen-, hydrogen-, and oxygen-bearing compounds, including organic molecules, and measure isotopes of carbon, hydrogen, oxygen, and noble gases in the atmosphere. DAN is located on the back of the rover and can detect subsurface hydrogen as a proxy of H_2O either in the form of ice or in mineral structures.

Curiosity has two instruments to characterize the modern environment. The Radiation Assessment Detector (RAD) measures high-energy radiation on the martian surface to evaluate the radiation environment for future human exploration of Mars. Finally, the Rover Environmental Monitoring System (REMS) is the rover's weather station, measuring atmospheric pressure, air and ground temperature, humidity, ultraviolet light, and wind speed and direction.

The Curiosity rover landed in Gale crater on August 6, 2012. Gale crater is an impact crater ~150 kilometers in diameter located near the martian equator along the boundary between older, cratered terrain to the south and younger, smooth plains to the north. It was selected from over 50 initially proposed landing sites during a series of landing site workshops in which NASA solicited input from the planetary science community on the scientific and engineering benefits and drawbacks of each landing site. The final four landing sites also included Mawrth Vallis, Holden crater, and Eberswalde crater. All four landing sites had layered sedimentary rocks containing phyllosilicates, indicating that there was once liquid water at those locations and they may have once been habitable. Although each of the landing sites would have satisfied the science criterion to study a site that has evidence for liquid water in the past, Gale crater was selected because of the diversity of ancient aqueous environments.

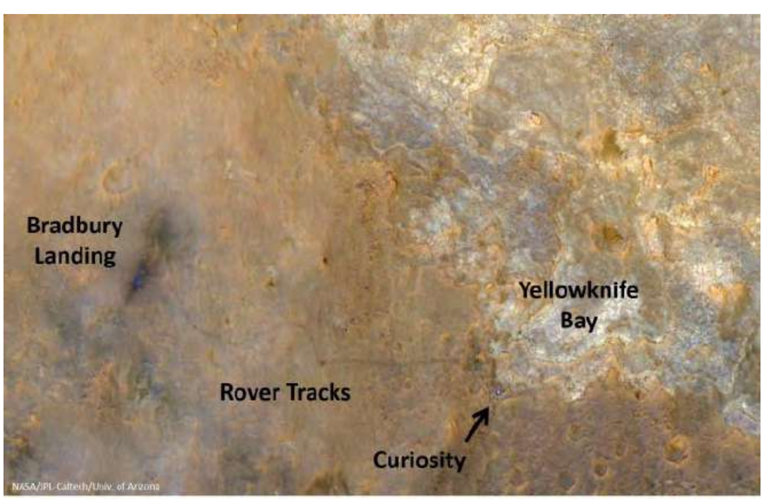


Curiosity's traverse through Sol 2108 with major waypoints listed. Inset shows rover location at time of writing. Credit: NASA/JPL-Caltech/Univ. of AZ/MSSS/USGS.

Curiosity was sent to Gale crater to study sedimentary rocks that were deposited ~3.5 Ga by rivers and lakes, evaluate changes in environments over time, and determine whether these environments would have been habitable to ancient microbial life. Gale crater contains a ~5 kilometer-tall mound of layered sedimentary rock in the center of the crater called Aeolis Mons (informally known as Mount Sharp). Orbiting spectrometers identified a variety of minerals in the lowest layers of Mount Sharp that formed from water-rock interactions. Phyllosilicates and the iron oxide mineral hematite were identified near the base of Mount Sharp (in the oldest sedimentary rocks) and sulfate salts were identified just above the phyllosilicate- and hematite-bearing rocks (in slightly younger sedimentary rocks). This suggests that the ancient sedimentary rocks in Gale crater preserve a variety of different environments that may have been habitable and that these rocks may help scientists better understand the dramatic climate change that occurred on Mars ~3.5 Ga. By driving up the lower layers of Mount Sharp, Curiosity can study how these environments changed over time.

Evidence for Ancient Rivers and Lakes at Gale Crater

Since landing ~6 years ago, Curiosity has driven over 19 kilometers. The first ~2 years of the mission were spent traversing the crater plains to reach the lower slopes of Mount Sharp. Almost all the rocks that the rover has encountered have been sedimentary and were deposited by either water (rivers, lakes, and deltas) or by wind. Even before landing in Gale crater, ancient streams and alluvial fans were discovered from orbit near the landing site. Some of these stream deposits were studied by Curiosity near the landing site thanks to the descent rockets (part of the incredible, never-before-executed Sky Crane maneuver), which blew away much of the surface dust and sediment. A coarse-grained sedimentary rock called conglomerate made up of rounded pebbles and sand was discovered near the landing site. The size of the pebbles indicates the rock was deposited by a stream that was up to 1 meter deep.



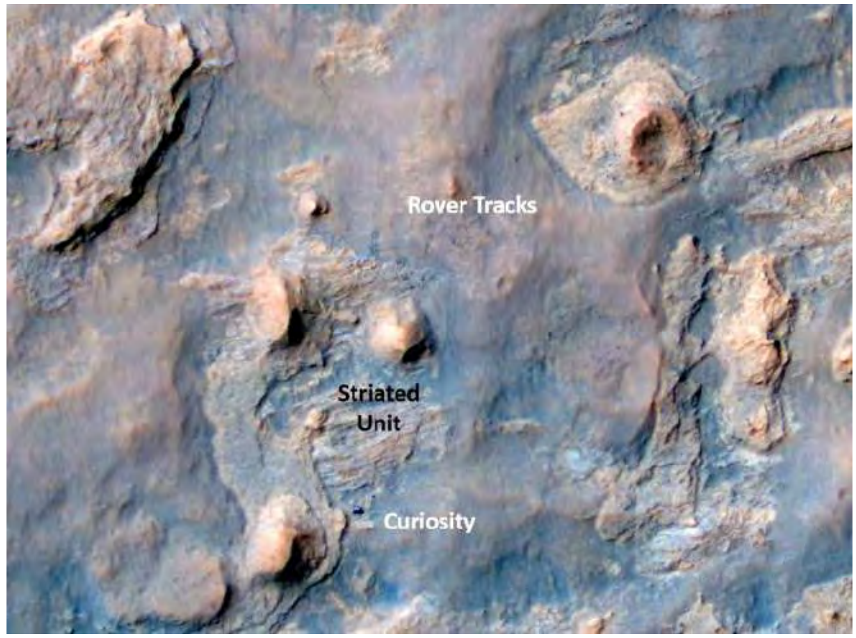
HiRISE image showing Curiosity's landing site, the rover investigating Yellowknife Bay, and the rover's tracks from the drive from Bradbury landing to Yellowknife Bay. Credit: NASA/JPL-Caltech/Univ. of Arizona.

From the landing site, Curiosity took a detour to the east (instead of driving to the southwest toward Mount Sharp) to study three different units identified from orbit at a location named Yellowknife Bay. Curiosity discovered very fine-grained sedimentary rock called mudstone at Yellowknife Bay, indicating that Yellowknife Bay was the site of an ancient lake. Features in the mudstone, like raised ridges and spherules, suggest that groundwater moved through the sediment before it was lithified.

After an extensive campaign at Yellowknife Bay, Curiosity drove to the southwest toward the lower slopes of Mount Sharp. Curiosity did another lengthy campaign at a region known as "The Kimberley," where many different units identified from orbit were located, including one named the Striated Unit. From the ground, the Striated Unit was made up of sandstone beds that were very gently dipping toward the center of the crater. These dipping beds are signatures of delta deposits, where rivers or streams flowed into lakes and the sediment that was transported by the rivers or streams fell out of suspension.

Curiosity reached the lower slopes of Mount Sharp in September 2014 upon arrival at the Pahrump Hills. The rocks of the Pahrump Hills were predominantly laminated mudstone, where individual layer thicknesses were between ~1 millimeter and 1 centimeter. Laminated mudstone is commonly produced by lake deposits. Since the start of Curiosity's ascent up Mount Sharp, laminated mudstone has been the most common rock type observed. Rare mud cracks indicate some drying of the lakes, but the persistent laminated mudstone for 300+ meters of vertical stratigraphy suggests that lakes were present for an extended period of time in Gale crater, perhaps for hundreds of thousands to a few millions of years. The sedimentary rocks of lower Mount Sharp also show evidence for groundwater, with the presence of concretions, spherules, and mineralized veins.

Based on the observation of conglomerate and dipping sandstone on the plains of Gale crater and laminated mudstone on lower Mount Sharp, Gale crater was once much wetter and Earth-like. Rivers and streams emanating from the crater rim flowed into lakes on the crater floor. We hypothesize that the rivers and streams formed from the melting of snow and ice on the crater rim because we have not yet discovered evidence that it rained on Mars. For instance, we have not seen rain drop imprints fossilized in the mudstone. In addition to abundant water on the surface, groundwater also moved through sediments before and after they were lithified, indicating Gale crater had a rich history of surface and subsurface water.



HiRISE image showing the Striated Unit at the Kimberley, Curiosity investigating the Striated Unit, and the rover's tracks. Credit: NASA/JPL-Caltech/Univ. of Arizona.

What was the Ancient Water like at Gale Crater?

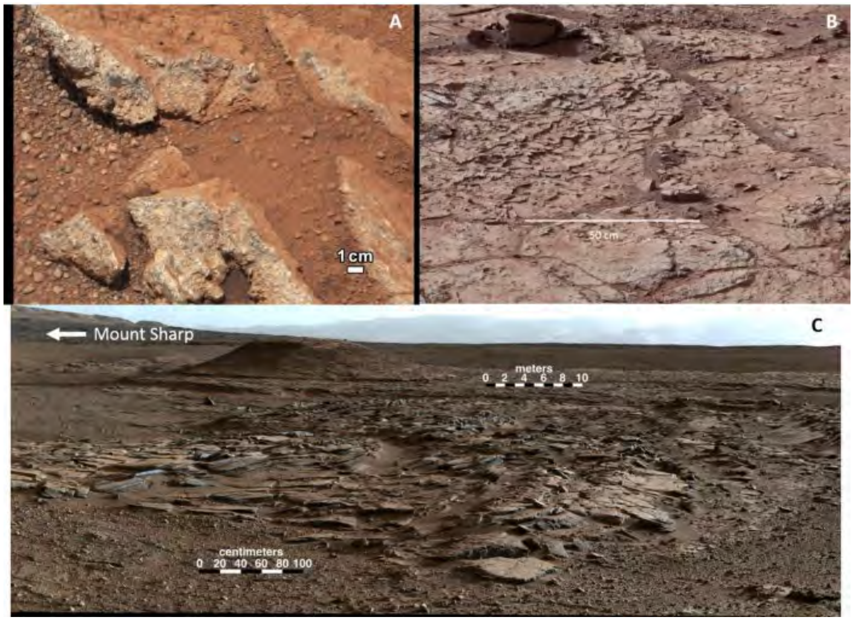
The geochemical and mineralogical composition of the sedimentary rocks in Gale crater can tell us very specific information about the ancient lake waters and groundwater and can help us determine whether or not these environments would have been habitable to microbial life. At the time of writing, Curiosity has drilled 16 rock samples, 12 of which were likely deposited by lakes or rivers. The igneous minerals that CheMin detects in the sedimentary rocks indicate that the igneous rocks surrounding Gale crater are primarily basaltic. Basalt is very low in SiO_2 and is the most common rock type found in Hawaii. It contains abundant plagioclase feldspar and pyroxene.

The minerals that form from water-rock interactions are those that tell us about past aqueous environments. Nearly all the mudstone deposits contain the clay mineral smectite, suggesting formation in water at near-neutral pH (although laboratory research has shown that smectite can form at moderately acidic to moderately basic pH). In addition to basaltic igneous minerals and smectite at Yellowknife Bay, CheMin discovered the iron oxide magnetite, which has both reduced and oxidized iron in its structure, and calcium (Ca)-sulfate in hairline veins (indicating formation after the lake sediments lithified). This mineral assemblage suggests the lake water at Yellowknife Bay had near-neutral pH, low salinity, and was not too oxidizing. The mudstone samples collected from the lower slopes of Mount Sharp have a very diverse mineralogy, indicating they preserve many different environments. Near the base of Mount Sharp, smectite and magnetite are prevalent with little to no Ca-sulfate, suggesting an environment similar to that of Yellowknife Bay. Moving up Mount Sharp into younger and younger rocks, magnetite gives way to the iron oxide mineral hematite, which has oxidized iron and no reduced iron in its structure; Ca-sulfate minerals are also prevalent in the sediment matrix (meaning it likely precipitated before the sediments lithified), and the smectite composition and structure changes slightly, indicating it was more altered by water than the smectite observed in Yellowknife Bay or Pahrump Hills. This change in mineralogy indicates that the water from which these minerals precipitated (lake water and/or groundwater) was more oxidizing and was more saline than the water that precipitated the mineral assemblage at Yellowknife Bay.

It can be difficult to determine whether the minerals that formed from water-rock interaction (like the smectite, iron oxides, and Ca-sulfate minerals) were precipitated from lake waters or from groundwater moving through the sediments. We can use textures in the rock as clues pointing toward the presence of groundwater, but we really need the rock samples in hand so that we can look at them under microscopes and examine the physical and chemical relationships between the minerals. SAM data from one sample drilled from the base of Mount Sharp has shown us that at least one mineral precipitated from groundwater long after the sediments were deposited by lakes. CheMin identified an iron sulfate mineral, jarosite, in the Mojave2 sample from the Pahrump Hills. Jarosite is an important environmental indicator because it forms in acid sulfate solutions with a pH of ~2–4. SAM performed krypton-argon age dating on the jarosite and determined it precipitated 2.12 ± 0.36 Ga, which is nearly 1.5 billion years after the lake sediments were deposited. This incredibly young age for the jarosite in Pahrump Hills tells us that there was a period of ~1.5 billion years during which water was present on the surface or near the subsurface of Gale crater (although the groundwater was likely present intermittently). This has big implications for the habitability of Gale crater.

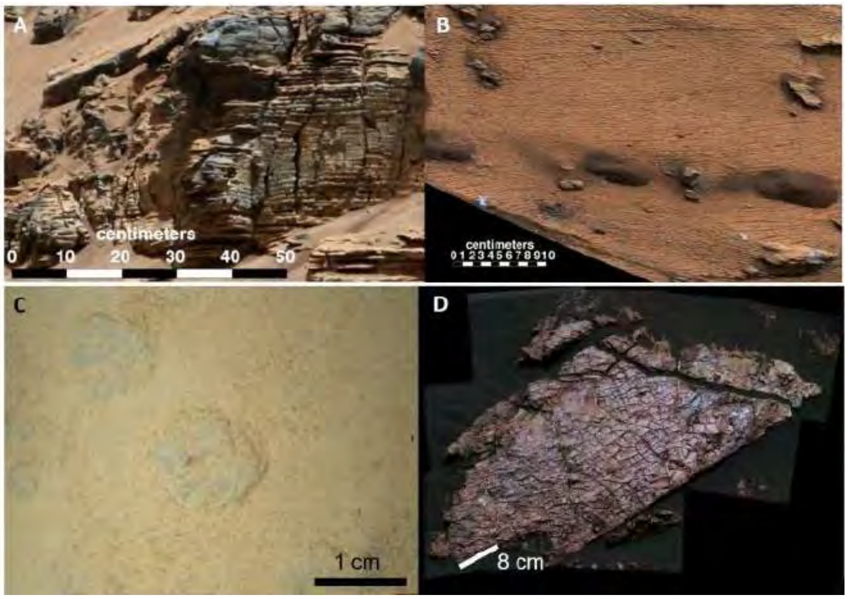
Was Gale Crater Ever Habitable?

An especially intriguing aspect of the identification of habitable environments in Gale crater ~3.5 Ga is that the oldest microbial fossils on Earth date to around the same time, so it is not unreasonable to think that microbes could have evolved on neighboring terrestrial planets that had similar environmental conditions. To determine whether Gale crater would have been habitable to microbial life, we need to consider the requirements for microbial life to thrive on Earth. Life as we know it on Earth requires liquid water, essential elements and nutrients, food/energy, and shelter from harmful radiation. The RAD instrument has shown that the surface radiation environment at Gale crater is too harsh for microbes to survive today, but ~3.5 Ga, Mars likely had a thicker atmosphere to help protect the surface from high-energy particles coming from space. Microbes could have also lived below the surface in lake sediments or fractures in the rock to protect themselves.



Images of outcrops on the plains of Gale crater. (a) Conglomerate near Curiosity's landing site. (b) Mudstone at Yellowknife Bay with raised ridges. (c) Dipping sandstone beds at the Kimberley. Credit: NASA/JPL-Caltech/MSSS.

The types of sedimentary rocks we find with Curiosity and the minerals we find in those rocks tell us there was a long history of liquid water at Gale crater. Lakes were likely present on the surface for hundreds of thousands to a few millions of years, and groundwater was present (at least intermittently) for ~1.5 billion years. The minerals we find suggest that some of the lake waters and groundwater would have been relatively fresh and some would have been more saline. However, we have not found evidence for hypersaline waters, and there are some microbes known as halophiles that have evolved to live in very saline conditions on Earth, so the lake and groundwater at Gale crater would have been fresh enough to support microbial activity.

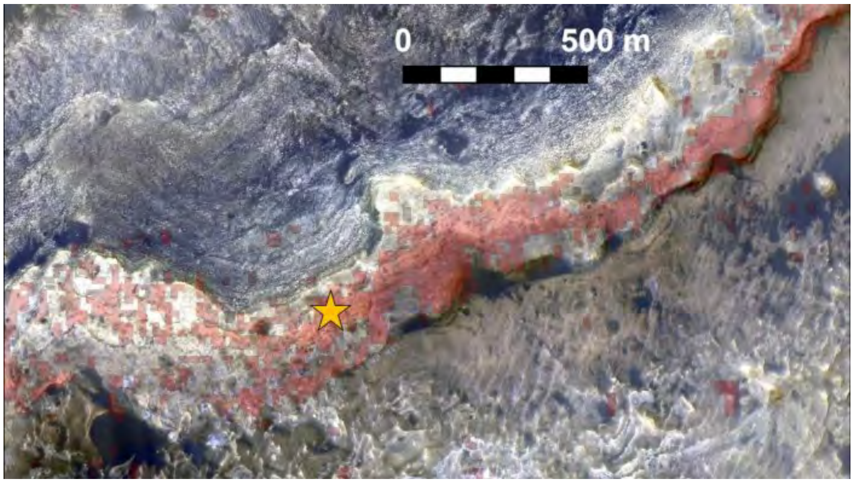


Images of outcrops from the lower slopes of Mount Sharp. (a),(b) Laminated mudstone deposits from the Pahrump Hills indicate sediment deposition from a lake. (c) Concretions from the base of the Pahrump Hills indicate groundwater. (d) Fossilized mud cracks. Credit: NASA/JPL-Caltech/MSSS.

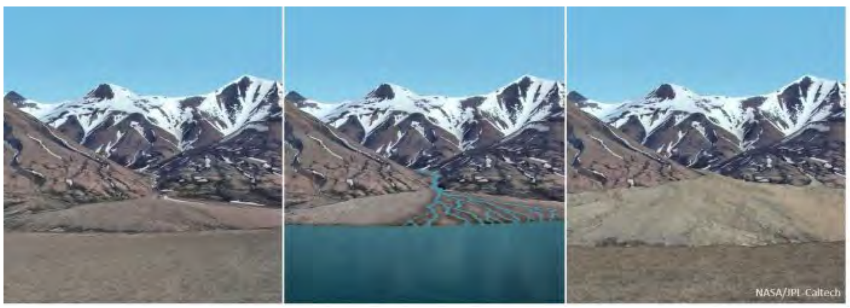
The main elements necessary for life are carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P), and sulfur (S), and these elements or compounds including these elements have been detected by the APXS, ChemCam, CheMin, SAM, and DAN instruments. Important micronutrients for microbes, like manganese (Mn), copper (Cu), zinc (Zn), and nickel (Ni), have also been detected by APXS and ChemCam. Chemotrophic microbes use elements in various states of oxidation as their source of energy, and some of the minerals we find, like magnetite, have elements in different oxidation states that could have been food for microbes. SAM has also detected organic molecules, which are the building blocks of life. Some of these organic molecules could have also been food sources for ancient microbes in Gale crater.

What's Next for Curiosity?

Curiosity is currently on the Vera Rubin Ridge (named for the famous American astronomer whose research provided evidence for the existence of dark matter). Vera Rubin Ridge was identified from orbit as a target of interest because it is enriched in the iron oxide mineral hematite. Hematite can form under a variety of conditions, many of which involve liquid water, so Curiosity is studying the ridge to determine how the hematite may have formed. Hematite was also studied by the Mars Exploration Rover Opportunity at Meridiani Planum. At Meridiani, hematite was in the form of spherules (or "blueberries"), indicating precipitation from groundwater. Curiosity has not detected similar blueberries, so the hematite is likely present in the sedimentary matrix. Laminated mudstone is very common on the ridge, suggesting deposition by lake water, but we don't yet know if the hematite precipitated from lake waters or groundwater. Curiosity is poised and ready to take its first drill sample from the Vera Rubin Ridge and deliver that sample to CheMin and SAM. The types of minerals that are found in association with the hematite will help us determine the conditions under which it formed. We anticipate that the Vera Rubin Ridge campaign will last through the summer of 2018, with additional samples drilled from the top of the ridge.



Vera Rubin Ridge from orbit. Red colors represent hematite mapped using data collected from orbital spectrometers. The star marks Curiosity's location at the time of writing. Credit: NASA/JPL-Caltech/JHUAPL/A. Fraeman.



Images, taken of Earth, altered to show what Gale crater may have looked like ~3.5 Ga, with alternating dry and wet periods. Wet periods occur from melting of snow and ice. Sediments are carried downstream and deposited in rivers, deltas, and lakes. Credit: NASA/JPL-Caltech.

After studying the Vera Rubin Ridge , Curiosity will continue to climb Mount Sharp and will investigate the phyllosilicate-bearing unit then the sulfate-bearing unit that were identified from orbit and were a primary driver for selecting Gale crater as the landing site. In the past 6 years, Curiosity has found evidence for a variety habitable environments based on the sedimentology, mineralogy, and geochemistry. As Curiosity studies these new units, the science team will continue to evaluate their habitability and place them in context with older units to characterize the changing environments on early Mars.

Learn More About the Curiosity Mission

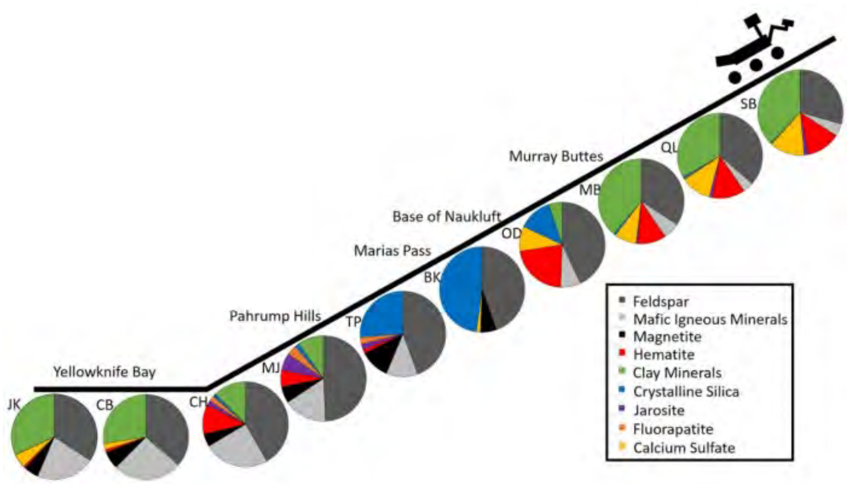
To follow Curiosity's progress and check out the latest images, visit:

https://mars.nasa.gov/msl/mission/overview/

https://mars.nasa.gov/msl/mission/whereistherovernow/

https://mars.nasa.gov/msl/multimedia/raw/

Here is a selection of recent scientific papers and abstracts for those readers who want more details on the scientific findings from the mission. This is not an exhaustive list, and the lead author of this article would be happy to recommend more reading to interested individuals.



Mineral abundances in samples from lake deposits measured from the CheMin instrument. Sample names: JK = John Klein, CB = Cumberland, CH = Confidence Hills, MJ = Mojave2, TP = Telegraph Peak, BK = Buckskin, OD = Oudam, MB = Marimba, QL = Quela, SB = Sebina. Credit: NASA/JPL-Caltech.

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Fraeman A. A., Edgar L. A., Grotzinger J. P., et al. (2018) Curiosity's investigation at Vera Rubin Ridge. *Lunar and Planetary Science XLIX,* Abstract #1557. Lunar and Planetary Institute, Houston.

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Hurowitz J. A., Grotzinger J. P., Fischer W. W., et al. (2017) Redox stratification of an ancient lake in Gale crater, Mars. *Science, 356(6341),* eaah6849.

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Rampe E. B., Ming D. W., Blake D. F., et al. (2017) Mineralogy of an ancient lacustrine mudstone succession from the Murray formation, Gale crater, Mars. *Earth and Planetary Science Letters* 471 (2017): 172-185.

Stein N., Grotzinger J. P., Schieber J., et al. (2018) Desiccation cracks provide evidence of lake drying on Mars, Sutton Island member, Murray formation, Gale Crater. *Geology, 46(6),* 515–518.

Thompson L. M., Fraeman A. A., Berger J. A., et al. (2018) APXS determined chemistry of the Vera Rubin (Hematite) Ridge, Gale Crater, Mars: Implications for hematite signature origin. *Lunar and Planetary Science XLIV,* Abstract #2826. Lunar and Planetary Institute, Houston.

About the Authors

Elizabeth Rampe (elizabeth.b.rampe@nasa.gov) is an Exploration Mission Scientist in the Astromaterials Research and Exploration Science Division at the NASA Johnson Space Center in Houston, Texas.

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

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

Dr. Paul Schenk, Scientific Editor (schenk@lpi.usra.edu)

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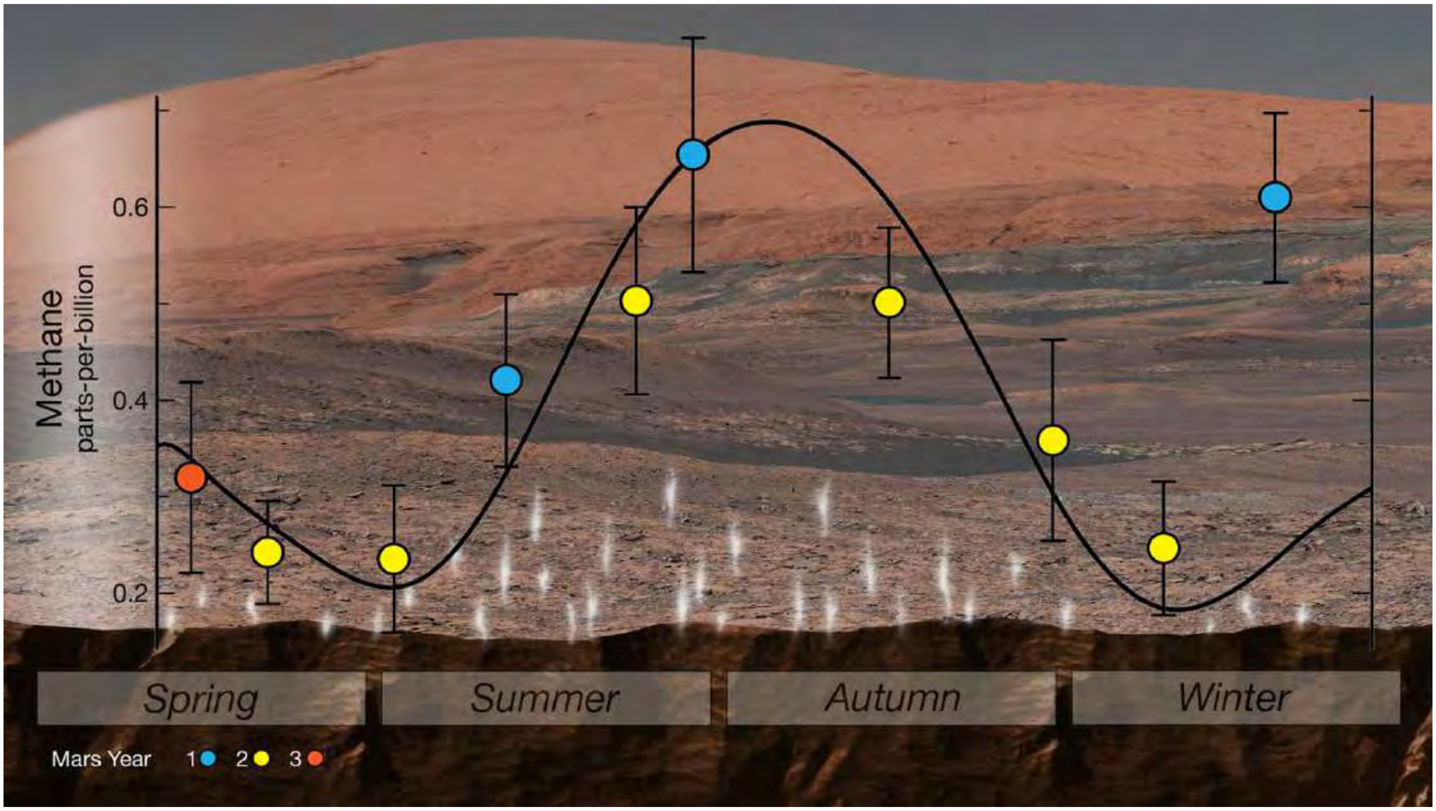
NASA Finds Ancient Organic Material, Mysterious Methane on Mars



NASA's Curiosity rover used an instrument called SAM (Sample Analysis at Mars) to detect seasonal changes in atmospheric methane in Gale Crater. The methane signal has been observed for nearly three martian years (nearly six Earth years), peaking each summer. Credit: NASA/JPL-Caltech.

NASA's Curiosity rover has found new evidence preserved in rocks on Mars that suggests the planet could have supported ancient life, and new evidence in the martian atmosphere that relates to the search for current life on the Red Planet. While not necessarily evidence of life itself, these findings are a good sign for future missions exploring the planet's surface and subsurface.

The new findings — "tough" organic molecules in 3-billion-year-old sedimentary rocks near the surface and seasonal variations in the levels of methane in the atmosphere — appear in the June 8 edition of *Science*.

Organic molecules contain carbon and hydrogen, and also may include oxygen, nitrogen, and other elements. While commonly associated with life, organic molecules also can be created by non-biological processes and are not necessarily indicators of life.

"With these new findings, Mars is telling us to stay the course and keep searching for evidence of life," said Thomas Zurbuchen, Associate Administrator for the Science Mission Directorate at NASA Headquarters in Washington. "I'm confident that our ongoing and planned missions will unlock even more breathtaking discoveries on the Red Planet."

"Curiosity has not determined the source of the organic molecules," said Jen Eigenbrode of NASA's Goddard Space Flight Center in Greenbelt, Maryland, who is lead author of one of the two new *Science* papers. "Whether it holds a record of ancient life, was food for life, or has existed in the absence of life, organic matter in martian materials holds chemical clues to planetary conditions and processes."

Although the surface of Mars is inhospitable today, there is clear evidence that in the distant past, the martian climate allowed liquid water — an essential ingredient for life as we know it — to pool at the surface. Data from Curiosity reveal that billions of years ago, a water lake inside Gale Crater held all the ingredients necessary for life, including chemical building blocks and energy sources.

"The martian surface is exposed to radiation from space. Both radiation and harsh chemicals break down organic matter," said Eigenbrode. "Finding ancient organic molecules in the top five centimeters of rock that was deposited when Mars may have been habitable bodes well for us to learn the story of organic molecules on Mars with future missions that will drill deeper."

Seasonal Methane Releases

In the second paper, scientists describe the discovery of seasonal variations in methane in the martian atmosphere over the course of nearly three Mars years, which is almost six Earth years. This variation was detected by Curiosity's Sample Analysis at Mars (SAM) instrument suite.

Water-rock chemistry might have generated the methane, but scientists cannot rule out the possibility of biological origins. Methane previously had been detected in Mars' atmosphere in large, unpredictable plumes. This new result shows that low levels of methane within Gale Crater repeatedly peak in warm, summer months and drop in the winter every year.

"This is the first time we've seen something repeatable in the methane story, so it offers us a handle in understanding it," said Chris Webster of NASA's Jet Propulsion Laboratory in Pasadena, California, lead author of the second paper. "This is all possible because of Curiosity's longevity. The long duration has allowed us to see the patterns in this seasonal 'breathing.'"

Finding Organic Molecules

To identify organic material in the martian soil, Curiosity drilled into sedimentary rocks known as mudstone from four areas in Gale Crater. This mudstone gradually formed billions of years ago from silt that accumulated at the bottom of the ancient lake. The rock samples were analyzed by SAM, which uses an oven to heat the samples (in excess of 900°F, or 500°C) to release organic molecules from the powdered rock.

SAM measured small organic molecules that came off the mudstone sample — fragments of larger organic molecules that don't vaporize easily. Some of these fragments contain sulfur, which could have helped preserve them in the same way sulfur is used to make car tires more durable, according to Eigenbrode.

The results also indicate organic carbon concentrations on the order of 10 parts per million or more. This is close to the amount observed in martian meteorites and about 100 times greater than prior detections of organic carbon on Mars' surface. Some of the molecules identified include thiophenes, benzene, toluene, and small carbon chains, such as propane or butene.

In 2013, SAM detected some organic molecules containing chlorine in rocks at the deepest point in the crater. This new discovery builds on the inventory of molecules detected in the ancient lake sediments on Mars and helps explain why they were preserved.

Finding methane in the atmosphere and ancient carbon preserved on the surface gives scientists confidence that NASA's Mars 2020 rover and ESA's (European Space Agency's) ExoMars rover will find even more organics, both on the surface and in the shallow subsurface.

These results also inform scientists' decisions as they work to find answers to questions concerning the possibility of life on Mars.

"Are there signs of life on Mars?" said Michael Meyer, lead scientist for NASA's Mars Exploration Program at NASA Headquarters. "We don't know, but these results tell us we are on the right track."

For more information, visit https://www.jpl.nasa.gov/news/news.php?feature=7154.

Red Planet Rover Set for Extreme Environment Workout

The structural model of the ExoMars rover, provided by ESA as part of the ESA/Roscosmos ExoMars mission, in which two out of the three wheel bogies can be seen facing the viewer. The black box toward the left is the drill box. The drill will be capable of accessing down to 2 meters (6 feet) below the surface to retrieve samples that may be better preserved against the harsh radiation experienced at the surface. Credit: Airbus Defence and Space UK.

A representative model of the ExoMars rover that will land on Mars in 2021 is beginning a demanding test campaign that will ensure it can survive the rigors of launch and landing, as well as operations under the environmental conditions of Mars.

ExoMars is a joint endeavor between ESA and Roscosmos, with the Trace Gas Orbiter already at Mars and beginning its science mission to look for atmospheric gases that may be linked to active geological or biological processes. The orbiter will relay the data collected by the rover back to Earth, a capability already demonstrated with communications relays to NASA's rovers currently on Mars.

The ExoMars rover will be the first of its kind to drill below the surface — down to 2 meters (6 feet) — and determine if evidence of life is buried underground, protected from the destructive radiation that impinges the surface today. Like any space mission, the rover's mechanical structure, along with its electrical and thermal components and its interfaces with the scientific instruments, have to be tested to verify that they can survive their journey in space and operations at the destination.

As such the rover structural and thermal model was recently transferred from Airbus Defence and Space in Stevenage, United Kingdom, to the Airbus site in Toulouse, France. The model will be shaken on a vibration table to ensure it can survive the intense juddering as the Proton rocket carries it into space. Furthermore, the rover model will be subjected to the shocks associated with entering another planet's atmosphere at high speed, as parachutes open, and with the touchdown onto the Red Planet's surface.

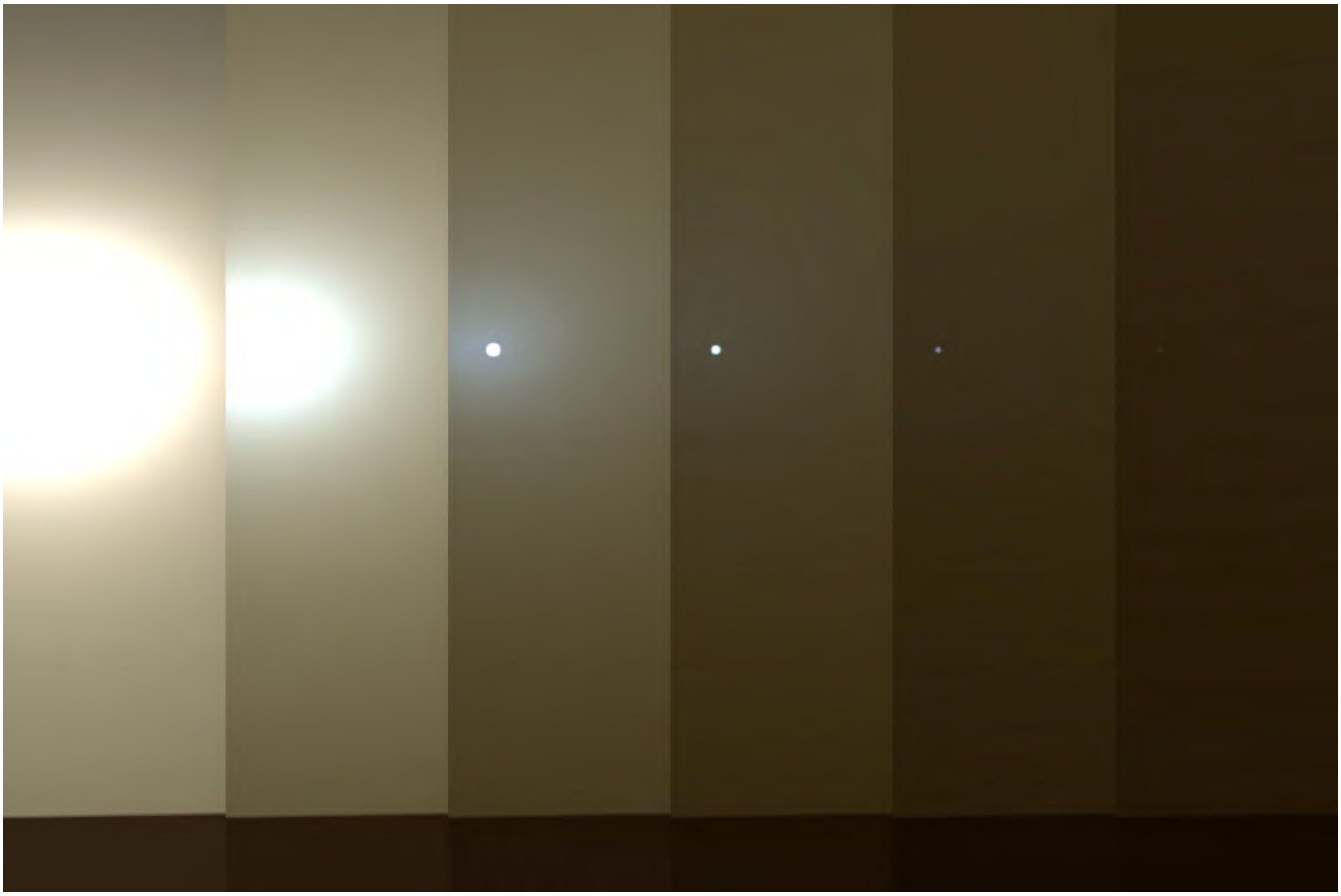
Two months of thermal tests will follow under Mars' atmospheric conditions to qualify the rover as able to withstand the frigid temperatures and large daily temperature variations on Mars. The tests will be conducted in a chamber to simulate the low atmospheric pressure of Mars — less than 1% of Earth's average sea level pressure — and its carbon dioxide-rich atmosphere. The rover will also need to operate at temperatures down to –120°C (–184°F). A closed compartment inside the rover, where martian soil samples will be analyzed, will be thermally controlled to maintain temperatures between 20°C (68°F) and –40°C (–40°F).

The current test campaign is expected to last until the beginning of August 2018. The rover model will then move to Lavochkin, Moscow, where it will be sealed inside a replica descent module and again subjected to vibration, shock, and thermal tests. Another test model will soon start an eight-month-long campaign focusing on the rover's movements and navigation over a variety of different ground types, ranging from fine-grained soil to larger boulders.

The mission will travel to Mars inside an aeroshell, with the rover mounted on a surface science platform. Once safely delivered to the Red Planet's surface, the landing platform will deploy its solar panels and ramps, and within a few days the rover will drive off the platform and begin its exciting exploration of Mars.

"This campaign kicks off a series of tests that will verify the mechanical and thermal design of the ExoMars rover, essential preparation that brings us a step closer to roving on the Red Planet," says Pietro Baglioni, ESA ExoMars rover team leader.

Opportunity Hunkers Down During Dust Storm



This series of images shows simulated views of a darkening martian sky blotting out the Sun from NASA's Opportunity rover's point of view, with the right side simulating Opportunity's current view in the global dust storm (June 2018). Credit: NASA/JPL-Caltech/TAMU.

Science operations for NASA's Opportunity rover have been temporarily suspended as it waits out a growing dust storm on Mars. The martian dust storm that has blotted out the Sun above Opportunity has continued to intensify. The storm, which was first detected on May 30, 2018, now blankets 35 million square kilometers (14 million square miles) of martian surface — a quarter of the planet — and is causing a dark, perpetual night to settle over the rover's location in Mars' Perseverance Valley.

The storm's atmospheric opacity — the veil of dust blowing around, which can blot out sunlight — is now much worse than a 2007 storm that Opportunity weathered. The previous storm had an opacity level, or tau, somewhere above 5.5; this new storm had an estimated tau of 10.8 as of June 10, 2018.

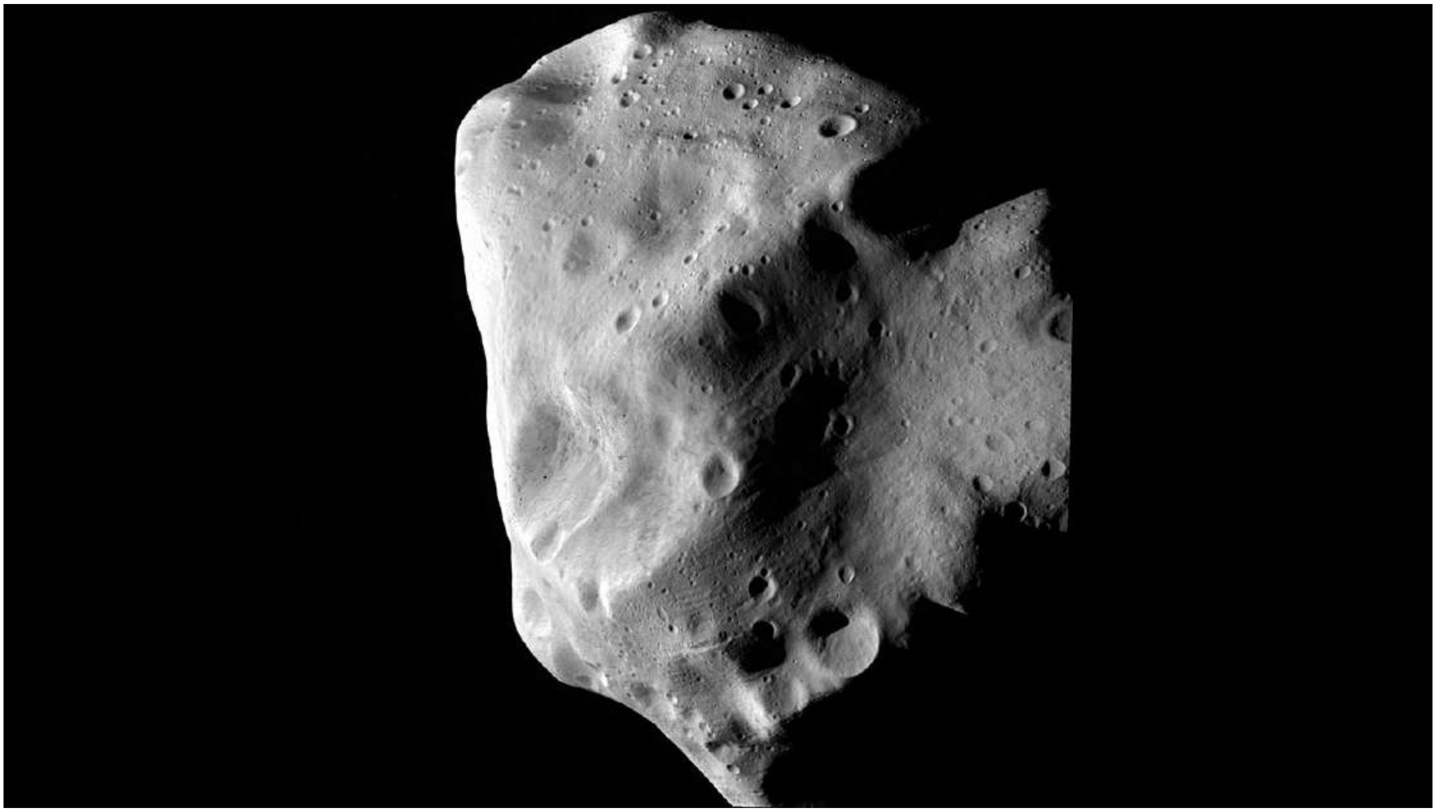
NASA engineers attempted to contact the Opportunity rover on June 14, but did not hear back from the nearly 15-year-old rover. The team is now operating under the assumption that the charge in Opportunity's batteries has dipped below 24 volts, and that the rover has entered low power fault mode, a condition where all subsystems, except a mission clock, are turned off. The rover's mission clock is programmed to wake the computer so it can check power levels. If the rover's computer determines that its batteries don't have enough charge, it will again put itself back to sleep. Due to an extreme amount of dust over Perseverance Valley, mission engineers believe it is unlikely the rover has enough sunlight to charge back up for at least the next several days. One saving grace of dust storms is that they can actually limit the extreme temperature swings experienced on the martian surface. The same swirling dust that blocks out sunlight also absorbs heat, raising the ambient temperature surrounding Opportunity.

This isn't Opportunity's first time hunkering down in bad weather. In 2007, a much larger storm covered the planet that led to two weeks of minimal operations, including several days with no contact from the rover to save power. The project's management prepared for the possibility that Opportunity couldn't balance low levels of power with its energy-intensive survival heaters, which protect its batteries from Mars' extreme cold. It's not unlike running a car in the winter so that the cold doesn't sap its battery charge.

Ultimately, the storm subsided, and Opportunity prevailed. The martian cold is believed to have resulted in the loss of Spirit, Opportunity's twin in the Mars Exploration Rover mission, back in 2010. Despite this, both rovers have vastly exceeded expectations as they were only designed to last 90 days each. Opportunity is in its 15th year; the team has operated the rover for more than 50 times longer than originally planned.

For more information, please visit https://mars.nasa.gov/mer/home/index.html.

NEOWISE Thermal Data Reveal Surface Properties of Over 100 Asteroids



Analysis of asteroids like Lutetia was used in the Josef Hanuš-led paper on asteroid thermophysical modeling. Lutetia is a large main-belt asteroid about 100 kilometers (62 miles) in diameter. Lutetia was visited by ESA's Rosetta spacecraft in 2010. Credit: ESA 2010 MPS.

Nearly all asteroids are so far away and so small that the astronomical community only knows them as moving points of light. The rare exceptions are asteroids that have been visited by spacecraft, a small number of large asteroids resolved by NASA's Hubble Space Telescope or large groundbased telescopes, or those that have come close enough for radar imaging.

When seen by optical telescopes, these individual sources of reflected sunlight can provide some very valuable and very basic information, including the asteroid's orbit, a ballpark estimate of its size, an approximation of its shape, and perhaps an idea of its physical makeup. However, to learn more about these elusive and important celestial objects requires a different type of instrument. Under the right circumstances, an infrared sensor can not only provide data on an asteroid's orbit and data that can be used to more accurately measure its size, but can also describe its chemical makeup and sometimes even its surface characteristics.

NASA's Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) spacecraft uses asteroid-hunting thermal sensors that allow an infrared view of asteroids without the obscuring effects of Earth's atmosphere. In a paper published recently in the journal *Icarus*, researchers led by Josef Hanuš, a scientist at the Astronomical Institute of Charles University, Prague, have made an in-depth analysis of more than 100 asteroids that have come under the temperature-sensing gaze of NEOWISE. This analysis tripled the number of asteroids that have undergone detailed "thermophysical" modeling of asteroid properties that vary with temperature. The results provide a more accurate glimpse into the surface properties of main-belt asteroids and also reinforce the capabilities of spacebased infrared observatories to accurately assess the sizes of asteroids.

Thermophysical modeling is a gold mine for asteroid researchers because it allows a more comprehensive analysis of the nature of asteroids. Not all asteroids are suitable for thermophysical modeling because the necessary raw datasets are not always available. However, Hanuš' team found 122 asteroids that had NEOWISE data, detailed models of their rotation states (how fast an object rotates around its axis and the orientation of the axis in space), and multi-faceted models of the asteroid's three-dimensional shape.

"Using archived data from the NEOWISE mission and our previously derived shape models, we were able to create highly detailed thermophysical models of 122 main-belt asteroids," said Hanuš, lead author of the paper. "We now have a better idea of the properties of the surface regolith and show that small asteroids, as well as fast rotating asteroids, have little, if any, dust covering their surfaces." (Regolith is the term for the broken rocks and dust on the surface.)

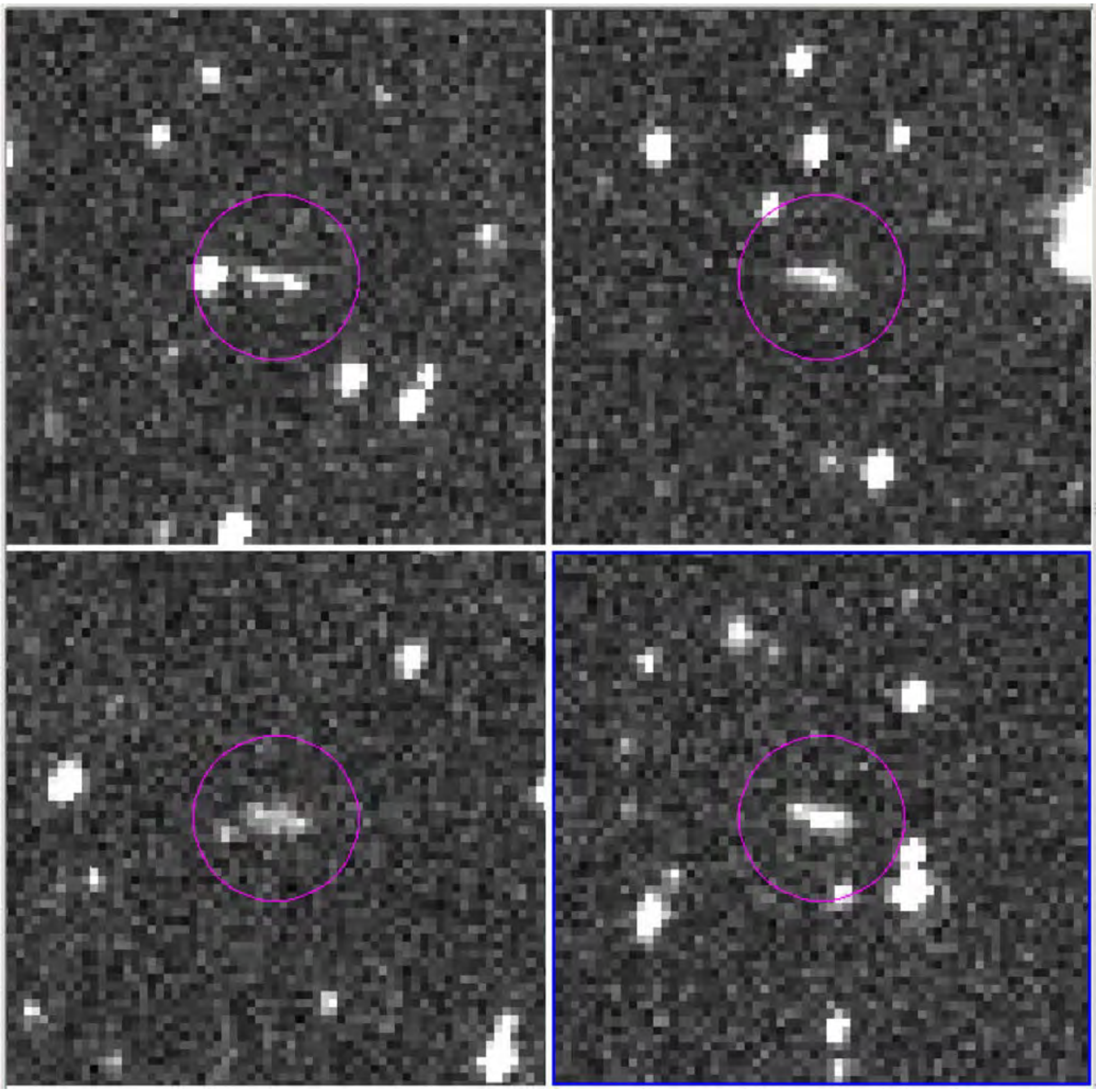
It could be difficult for fast-rotating asteroids to retain very fine regolith grains because their low gravity and high spin rates tend to fling small particles off their surfaces and into space. Also, it could be that fast-rotating asteroids do not experience large temperature changes because the Sun's rays are more rapidly distributed across their surfaces. That would reduce or prevent the thermal cracking of an asteroid's surface material that could cause the generation of fine grains of regolith. Hanuš' team also found that their detailed calculations for estimated sizes of the asteroids they studied were consistent with those of the same asteroids calculated by the NEOWISE team using simpler models.

"With the asteroids for which we were able to gather the most information from other sources, our calculations of their sizes were consistent with the radiometrically-derived values performed by the NEOWISE team," said Hanuš. "The uncertainties were within 10% between the two sets of results."

"This is an important example of how spacebased infrared data can accurately characterize asteroids," said Alan Harris, a senior scientist at the German Aerospace Center (DLR) based in Berlin, Germany, who specializes in thermal modeling of asteroids but was not involved with the study. "NEOWISE is leading the way in demonstrating the value of spacebased infrared observatories for asteroid and near-Earth object discovery and characterization, both vital to our understanding these important inhabitants of our solar system."

For more information, please visit https://www.nasa.gov/mission_pages/neowise/main/index.html.

Tiny Asteroid Discovered in June Disintegrates Hours Later Over Southern Africa



These are the discovery observations of asteroid 2018 LA from the Catalina Sky Survey, taken June 2, 2018. About eight hours after these images were taken, the asteroid entered Earth's atmosphere (about 9:44 a.m. PDT, 12:44 p.m. EDT, 16:44 UTC, 6:44 p.m. local Botswana time), and disintegrated in the upper atmosphere near Botswana, Africa.

A boulder-sized asteroid designated 2018 LA was discovered Saturday morning, June 2, 2018, and was determined to be on a collision course with Earth, with impact just hours away. Because it was very faint, the asteroid was estimated to be only about 2 meters (6 feet) across, which is small enough that it was expected to safely disintegrate in Earth's atmosphere. Saturday's asteroid was first discovered by the NASA-funded Catalina Sky Survey, located near Tucson and operated by the University of Arizona.

Although there was not enough tracking data to make precise predictions ahead of time, a swath of possible locations was calculated stretching from Southern Africa, across the Indian Ocean, and onto New Guinea. Reports of a bright fireball above Botswana, Africa, early Saturday evening match up with the predicted trajectory for the asteroid. The asteroid entered Earth's atmosphere at the high speed of 17 kilometers per second (10 miles per second or 38,000 miles per hour) at about 16:44 UTC (9:44 a.m. PDT, 12:44 p.m. EDT, 6:44 p.m. local Botswana time) and disintegrated several miles above the surface, creating a bright fireball that lit up the evening sky. The event was witnessed by a number of observers and was caught on webcam video.

When it was first detected, the asteroid was nearly as far away as the Moon's orbit, although that was not initially known. The asteroid appeared as a streak in the series of time-exposure images taken by the Catalina telescope. As is the case for all asteroid-hunting projects, the data were quickly sent to the Minor Planet Center in Cambridge, Massachusetts, which calculated a preliminary trajectory indicating the possibility of an Earth impact. The data were in turn sent to the Center for Near-Earth Object Studies (CNEOS) at NASA's Jet Propulsion Laboratory in Pasadena, California, where the automated Scout system also found a high probability that the asteroid was on an impact trajectory. Automated alerts were sent out to the community of asteroid observers to obtain further observations, and to the Planetary Defense Coordination Office at NASA Headquarters in Washington. However, since the asteroid was determined to be so small and therefore harmless, no further impact alerts were issued by NASA.

"This was a much smaller object than we are tasked to detect and warn about," said Lindley Johnson, Planetary Defense Officer at NASA Headquarters. "However, this real-world event allows us to exercise our capabilities and gives some confidence our impact prediction models are adequate to respond to the potential impact of a larger object."

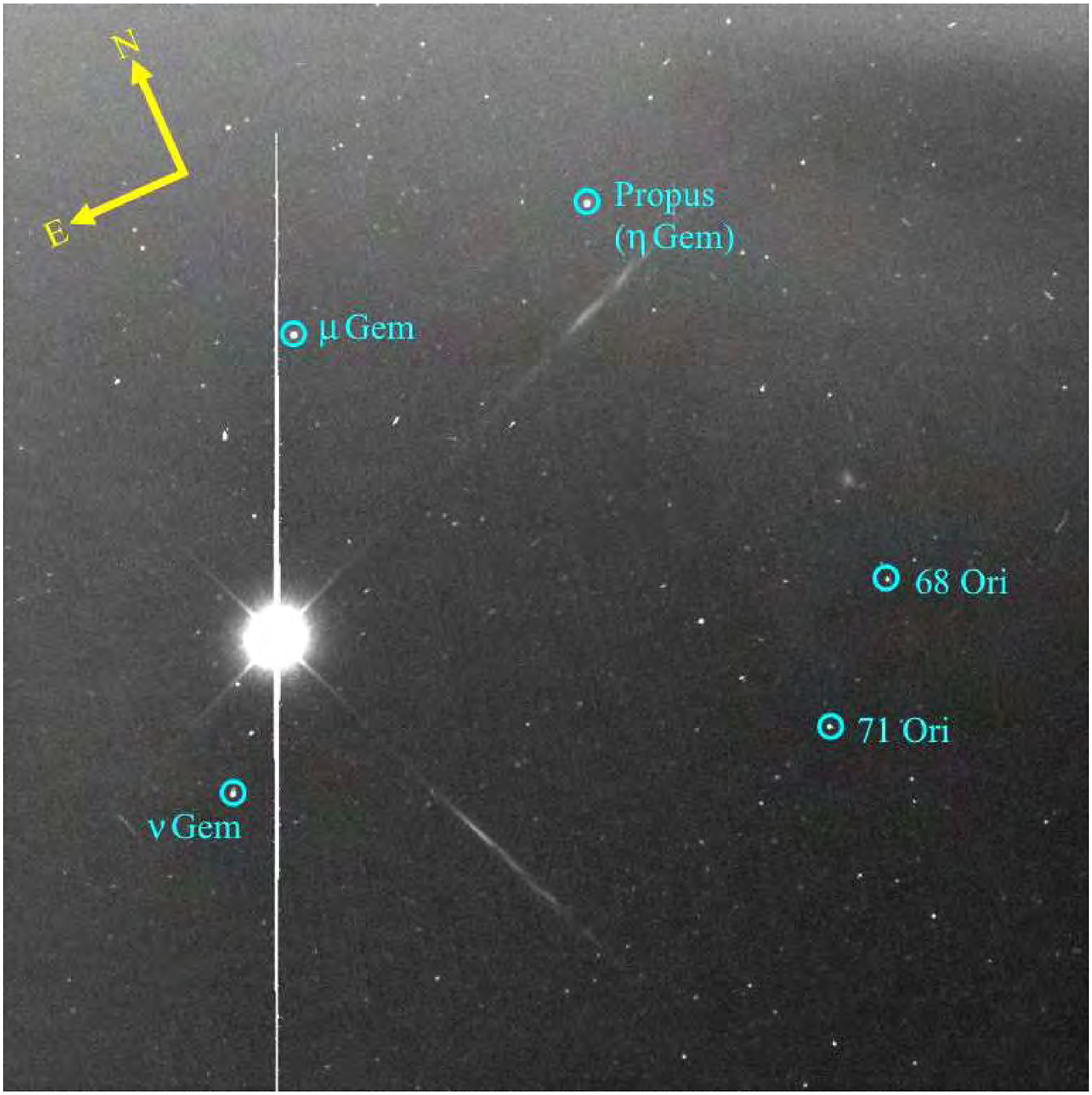
The ATLAS asteroid survey obtained two additional observations hours before impact, which were used by Scout to confirm the impact would occur, and narrowed down the predicted location to southern Africa. Infrasound data collected just after the impact clearly detected the event from one of the listening stations deployed as part of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty. The signal is consistent with an atmospheric impact over Botswana.

"The discovery of asteroid 2018 LA is only the third time that an asteroid has been discovered to be on an impact trajectory, said Paul Chodas, manager of the Center for Near-Earth Object Studies (CNEOS) at JPL. "It is also only the second time that the high probability of an impact was predicted well ahead of the event itself."

The first event of this kind was the impact of asteroid 2008 TC3, which lit up the predawn sky above Northern Sudan on October 7, 2008. That was a slightly larger asteroid (about 4 meters or 13 feet in size), and it was discovered a full 19 hours before impact, allowing for a large number of follow-up observations and a very precise trajectory to be calculated. The second predicted impact event was for asteroid 2014 AA, which was discovered only a few hours before impact on January 1, 2014, in the Atlantic Ocean, leaving too little time for follow-up observations. The Catalina Sky Survey has been responsible for discovering all three of these small asteroids on impact trajectories, and all on the watch of the same observer, Richard Kowalski.

For more information, visit https://www.jpl.nasa.gov/news/news.php?feature=7148.

RYUGU SEEN FROM A DISTANCE OF 2600 KILOMETERS

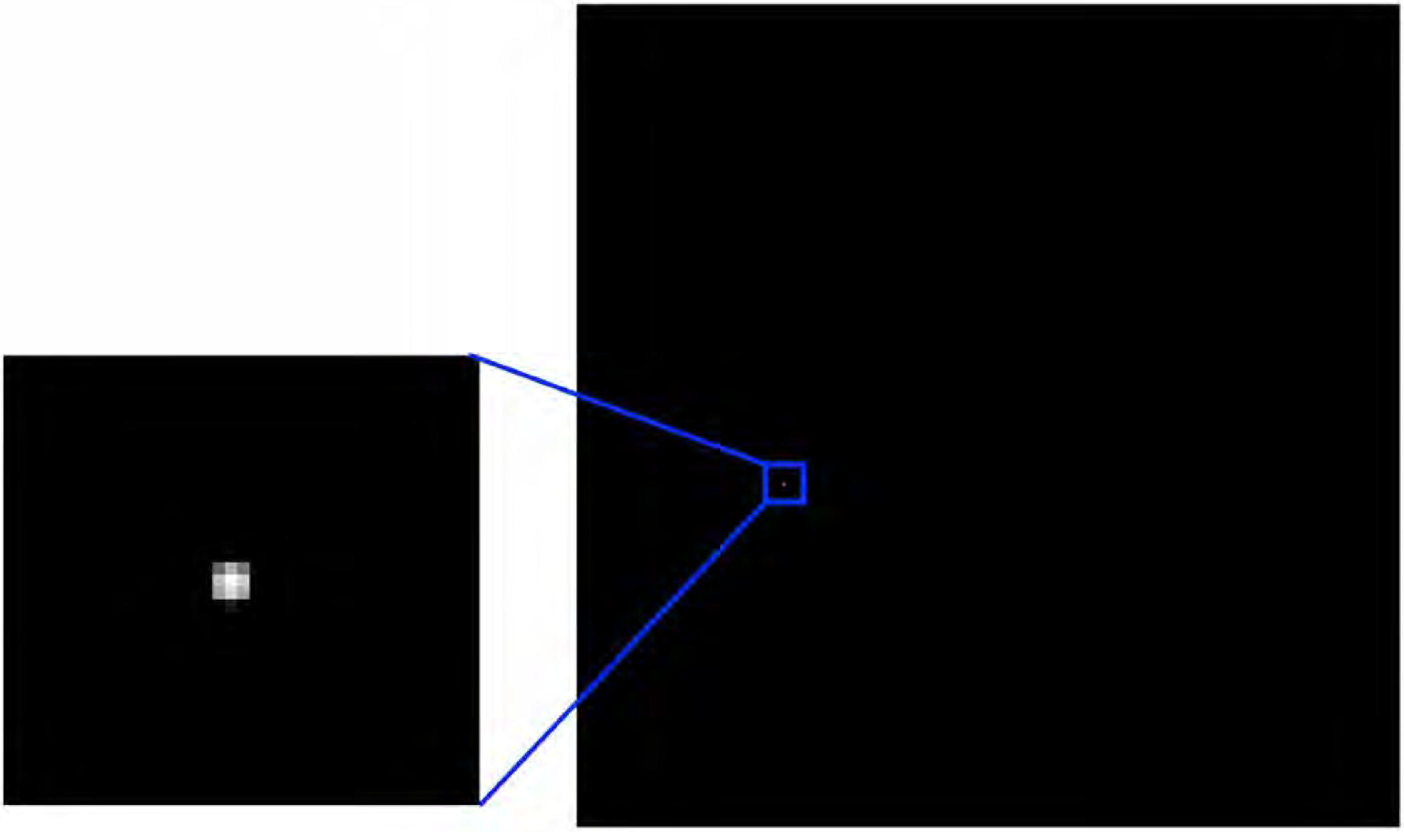


Ryugu photographed using the ONC-T. This photograph was taken on June 6, 2018, at around 04:15 JST. The field of view is 6.3° × 6.3°, and the exposure time is 178 seconds. From the spacecraft, Ryugu can be seen in the direction of the constellation, Gemini (Gem). Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University. ONC team: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST.

On June 3, 2018, ion engine operation was completed and the final approach to the asteroid Ryugu began. By photographing the asteroid with the Optical Navigation Camera, optical navigation (precisely "hybrid navigation using optical and radiometric observations") can be used to approach Ryugu while accurately estimating the trajectory of the Hayabusa2 spacecraft and asteroid.

The image above was taken with the ONC-T (Optical Navigation Camera-Telescopic) on June 6, 2018, at approximately 04:15 JST from the spacecraft in the direction of Ryugu. Ryugu appears extremely bright due to a long exposure time of 178 seconds, which was used in order to image background stars. Because of this, Ryugu has become blurred, and smears are generated. The brightness of Ryugu here is about –5 magnitude (a brightness scale used for stars).

In order to image Ryugu properly, a shorter exposure time is needed. The image below was taken at approximately the same time with an exposure time of about 0.09 seconds. A point is seen on Ryugu without any stars in the background. An enlargement of that part of the image is seen on the left side, with the image of Ryugu being about 3 pixels in diameter.

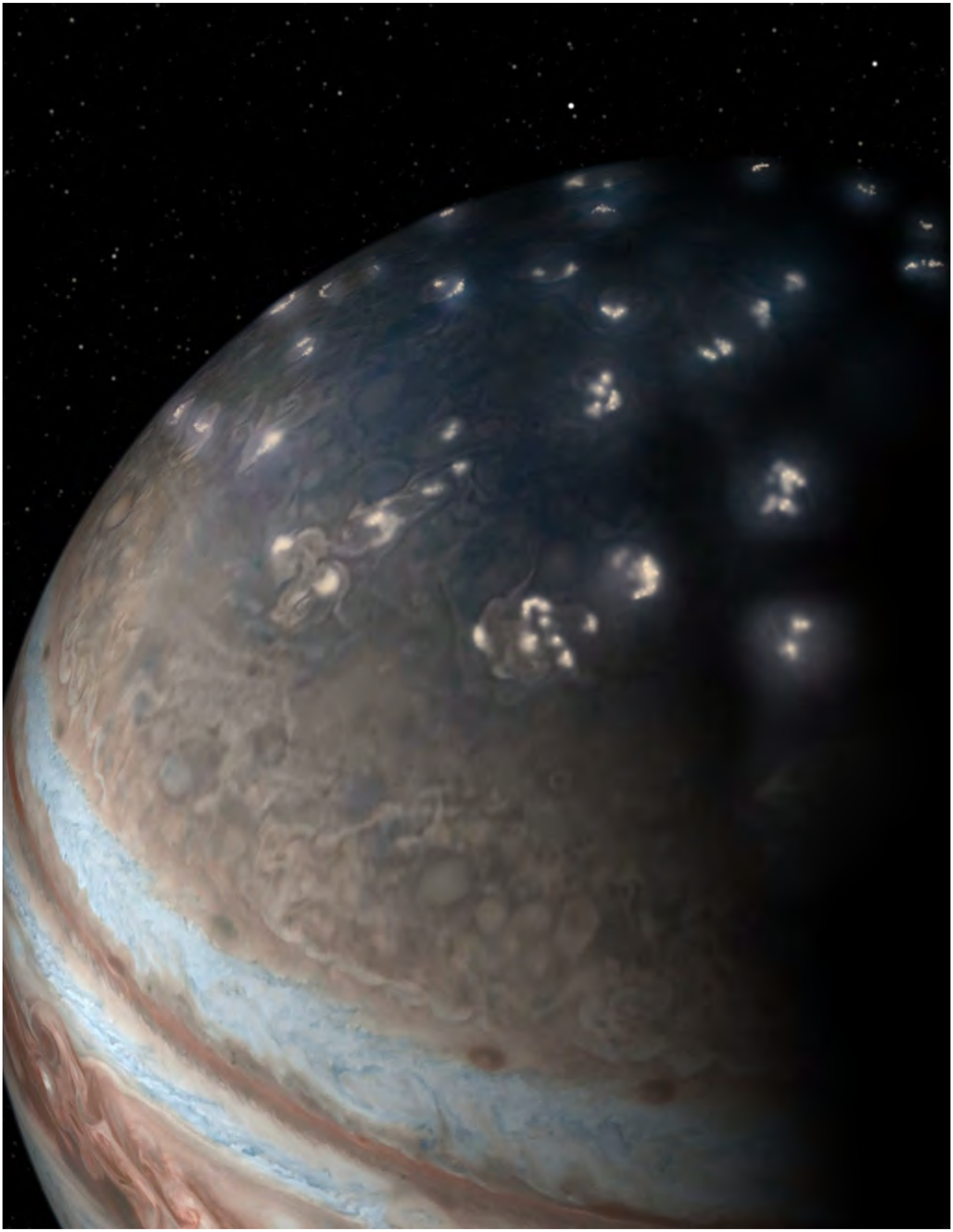


Ryugu photographed using the ONC-T. The photograph was taken on June 6, 2018, at around 04:15 JST. The field of view is 6.3° × 6.3°, and the exposure time is 0.09 seconds. Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University. ONC team: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST.

The distance from the spacecraft to Ryugu at the time the images were taken is about 2600 kilometers (1615 miles). In the ONC-T image, one pixel is about 22 arcseconds. Therefore, the length of one pixel would be approximately 0.3 kilometers (0.19 miles). This means we still cannot yet know the shape of the asteroid.

For more information, please visit http://www.hayabusa2.jaxa.jp/topics/20180607_e/.

Juno Solves 39-Year-Old Mystery of Jupiter Lightning



This artist's concept of lightning distribution in Jupiter's northern hemisphere incorporates a JunoCam image with artistic embellishments. Data from NASA's Juno mission indicates that most of the lightning activity on Jupiter is near its poles. Credit: NASA/JPL-Caltech.

Ever since NASA's Voyager 1 spacecraft flew past Jupiter in March 1979, scientists have wondered about the origin of Jupiter's lightning. That encounter confirmed the existence of jovian lightning, which had been theorized for centuries. However, when the venerable explorer hurtled by, the data showed that the lightning-associated radio signals didn't match the details of the radio signals produced by lightning here on Earth. In a new paper published in *Nature*, scientists from NASA's Juno mission describe the ways in which lightning on Jupiter is actually analogous to Earth's lightning.

"No matter what planet you're on, lightning bolts act like radio transmitters — sending out radio waves when they flash across a sky," said Shannon Brown of NASA's Jet Propulsion Laboratory in Pasadena, California, a Juno scientist and lead author of the paper. "But until Juno, all the lightning signals recorded by spacecraft [Voyagers 1 and 2, Galileo, Cassini] were limited to either visual detections or from the kilohertz range of the radio spectrum, despite a search for signals in the megahertz range. Many theories were offered up to explain it, but no one theory could ever get traction as the answer."

Enter Juno, which has been orbiting Jupiter since July 4, 2016. Among its suite of highly sensitive instruments is the Microwave Radiometer Instrument (MWR), which records emissions from the gas giant across a wide spectrum of frequencies. "In the data from our first eight flybys, Juno's MWR detected 377 lightning discharges," said Brown. "They were recorded in the megahertz as well as gigahertz range, which is what you can find with terrestrial lightning emissions. We think the reason we are the only ones who can see it is because Juno is flying closer to the lightning than ever before, and we are searching at a radio frequency that passes easily through Jupiter's ionosphere." While the revelation showed how Jupiter lightning is similar to Earth's, the new paper also notes that where these lightning bolts flash on each planet is actually quite different.

"Jupiter lightning distribution is inside out relative to Earth," said Brown. "There is a lot of activity near Jupiter's poles but none near the equator. You can ask anybody who lives in the tropics — this doesn't hold true for our planet."

Why do lightning bolts congregate near the equator on Earth and near the poles on Jupiter? Follow the heat. Earth derives the vast majority of its heat externally from solar radiation, courtesy of our Sun. Because our equator bears the brunt of this sunshine, warm moist air rises (through convection) more freely there, which fuels towering thunderstorms that produce lightning.

Jupiter's orbit is five times farther from the Sun than Earth's orbit, which means that the giant planet receives 25 times less sunlight than Earth. Even though Jupiter's atmosphere derives the majority of its heat from within the planet itself, this doesn't render the Sun's rays irrelevant. They do provide some warmth, heating up Jupiter's equator more than the poles — just as they heat up Earth. Scientists believe that this heating at Jupiter's equator is just enough to create stability in the upper atmosphere, inhibiting the rise of warm air from within. The poles, which do not have this upper-level warmth and, therefore, no atmospheric stability, allow warm gases from Jupiter's interior to rise, driving convection and creating the ingredients for lightning.

"These findings could help to improve our understanding of the composition, circulation, and energy flows on Jupiter," said Brown. Another question looms. "Even though we see lightning near both poles, why is it mostly recorded at Jupiter's north pole?"

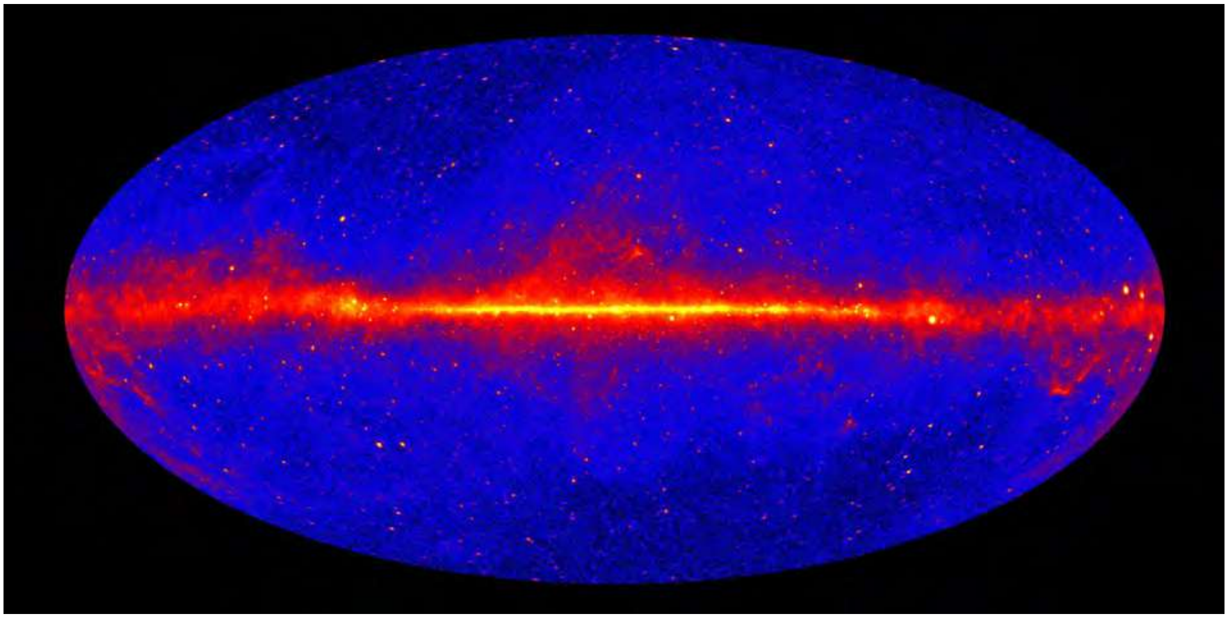
In a second Juno lightning paper published in *Nature Astronomy*, Ivana Kolmašová of the Czech Academy of Sciences, Prague, and colleagues presents the largest database of lightning-generated, low-frequency radio emissions around Jupiter (whistlers) to date. The dataset of more than 1600 signals, collected by Juno's Waves instrument, is almost 10 times the number recorded by Voyager 1. Juno detected peak rates of four lightning strikes per second (similar to the rates observed in thunderstorms on Earth), which is six times higher than the peak values detected by Voyager 1.

"These discoveries could only happen with Juno," said Scott Bolton, principal investigator of Juno from the Southwest Research Institute, San Antonio. "Our unique orbit allows our spacecraft to fly closer to Jupiter than any other spacecraft in history, so the signal strength of what the planet is radiating out is a thousand times stronger. Also, our microwave and plasma wave instruments are state-of-the-art, allowing us to pick out even weak lightning signals from the cacophony of radio emissions from Jupiter."

NASA's Juno spacecraft will make its 13th science flyby over Jupiter's mysterious cloud tops on July 16, 2018.

For more information, please visit https://www.jpl.nasa.gov/news/news.php?feature=7151.

NASA's FERMI Satellite Celebrates 10 Years of Discoveries



The sharper, more detailed all-sky map produced by the Fermi Gamma-ray Space Telescope using nine years of data collected from 2008 to 2017. Brighter colors indicated a larger number of gamma rays. Credit: NASA/DOE/Fermi LAT Collaboration.

On June 11, 2018, NASA's Fermi Gamma-ray Space Telescope celebrated a decade of using gamma rays, the highest-energy form of light in the cosmos, to study black holes, neutron stars, and other extreme cosmic objects and events.

"Fermi's first 10 years have produced numerous scientific discoveries that have revolutionized our understanding of the gamma-ray universe," said Paul Hertz, Astrophysics Division director at NASA Headquarters in Washington.

By scanning the sky every three hours, Fermi's main instrument, the Large Area Telescope (LAT), has observed more than 5000 individual gamma-ray sources, including an explosion called GRB 130427A, the most powerful gamma-ray burst scientists have detected.

In 1949, Enrico Fermi — an Italian-American pioneer in high-energy physics and Nobel laureate for whom the mission was named — suggested that cosmic rays, particles traveling at nearly the speed of light, could be propelled by supernova shock waves. In 2013, Fermi's LAT used gamma rays to prove these stellar remnants are at least one source of the speedy particles. Fermi's all-sky map, produced by the LAT, has revealed two massive structures extending above and below the plane of the Milky Way. These two "bubbles" span 50,000 light-years and were probably produced by the supermassive black hole at the center of the galaxy only a few million years ago.

"The astronomy of gamma rays is the science of extremes," said Julie McEnery, the Fermi project scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "Extreme gravity, extreme magnetic fields — Fermi has opened a window on to some of the most interesting physics and structures in the universe."

The Gamma-ray Burst Monitor (GBM), Fermi's secondary instrument, can see the entire sky at any instant, except the portion blocked by Earth. The satellite has observed over 2300 gamma-ray bursts, the most luminous events in the universe. Gamma-ray bursts occur when massive stars collapse or neutron stars or black holes merge and drive jets of particles at nearly the speed of light. In those jets, matter travels at different speeds and collides, emitting gamma rays.

On August 17, 2017, Fermi detected a gamma-ray burst from a powerful explosion in the constellation, Hydra. At almost the same time, the National Science Foundation's Laser Interferometer Gravitational-wave Observatory detected ripples in space-time from the same event, the merger of two neutron stars. This was the first time light and gravitational waves were detected from the same source. Scientists also used another gamma-ray burst detected by Fermi to confirm Einstein's theory that space-time is smooth and continuous. The GBM has also spotted over 5000 terrestrial gamma-ray flashes in Earth's atmosphere associated with thunderstorms, as well as the particles of antimatter those flashes can produce.

"Fermi has fundamentally improved our understanding of how the universe operates," said David Thompson, a Fermi deputy project scientist at Goddard. "This spacecraft has both provided evidence for long-cherished theories and has also forced the scientific community to reevaluate some of its assumptions."

Space can be a difficult working environment. On April 3, 2012, Fermi dodged a potential collision with Cosmos 1805, a defunct Soviet Cold War spy satellite, when the team fired Fermi's decommissioning thrusters to move it to safety. Fermi experienced its first hardware failure on March 16, 2018, when one of its solar panels became stuck. The Fermi team has adopted a new observation strategy to accommodate the jammed solar panel, and both instruments continue to scan the gamma-ray universe.

"The Fermi observatory has so much flexibility that this glitch has only minor impact on science operations," McEnery said. "Fermi is well prepared to continue operations for many years, and we look forward to many more discoveries about the high-energy universe."

For more information on Fermi, visit https://www.nasa.gov/fermi.

A Space Ant Fires its Lasers

The Ant Nebula, as imaged by the NASA/ESA Hubble Space Telescope, resembles the head and body of a garden ant. In reality, it is the result of a dying Sun-like star and complex interactions of material at its heart. Credit: NASA/ESA/Hubble Heritage Team (STScI/AURA).

A rare phenomenon connected to the death of a star has been discovered in observations made by ESA's Herschel Space Observatory — an unusual laser emission from the spectacular Ant Nebula, which suggests the presence of a double star system hidden at its heart.

When low- to middle-weight stars like our Sun approach the end of their lives, they eventually become dense, white dwarf stars. In the process, they cast off their outer layers of gas and dust into space, creating a kaleidoscope of intricate patterns known as a planetary nebula.

The infrared Herschel observations have shown that the dramatic demise of the central star in the core of the Ant Nebula is even more theatrical than implied by its colorful appearance in visible images, such as those taken by the NASA/ESA Hubble Space Telescope. As revealed by the new data, the Ant Nebula also beams intense laser emission from its core.

While lasers in everyday life today might mean special visual effects in music concerts, in space, focused emission is detected at different wavelengths under specific conditions. Only a few of these space infrared lasers are known. By coincidence, astronomer Donald Menzel, who first observed and classified this particular planetary nebula in the 1920s (it is officially known as Menzel 3 after him), was also one of the first to suggest that in certain conditions natural light amplification by stimulated emission of radiation could occur in gaseous nebulae. This was well before the discovery and first successful operation of lasers in laboratories in 1960, an occasion that is now celebrated annually on May 16 as the International Day of Light.

"When we observe Menzel 3, we see an amazingly intricate structure made up of ionized gas, but we cannot see the object in its center producing this pattern," says Isabel Aleman, lead author of a paper describing the new results. "Thanks to the sensitivity and wide wavelength range of the Herschel observatory, we detected a very rare type of emission called hydrogen recombination line laser emission, which provided a way to reveal the nebula's structure and physical conditions."

This kind of laser emission needs very dense gas close to the star. Comparison of the observations with models found that the density of the laser-emitting gas is around 10,000 times higher than that of the gas seen in typical planetary nebulae and in the lobes of the Ant Nebula itself. Normally, the region close to the dead star — close in this case being about the distance of Saturn from the Sun — is quite empty because most of its material is ejected outward. Any lingering gas would soon fall back onto it.

“The only way to keep gas close to the star is if it is orbiting around it in a disc,” says co-author Albert Zijlstra. “In this case, we have actually observed a dense disc in the very center that is seen approximately edge-on. This orientation helps to amplify the laser signal. The disc suggests the white dwarf has a binary companion, because it is hard to get the ejected gas to go into orbit unless a companion star deflects it in the right direction.”

Astronomers have not yet seen the expected second star, but they think that the mass from the dying companion star is being ejected and then captured by the compact central star of the original planetary nebula, producing the disc where the laser emission is produced.

“We used Herschel to characterize various components of gas and dust in nebula around old stars, but we were not necessarily looking for a laser phenomenon,” adds Toshiya Ueta, principal investigator of the Herschel Planetary Nebula Survey project. “Such emission has only been identified in a handful of objects before; this was a remarkable discovery that we did not anticipate. There is certainly more to stellar nebulae than meets the eye!”

“This study suggests that the distinctive Ant Nebula as we see it today was created by the complex nature of a binary star system, which influences the shape, chemical properties, and evolution in these final stages of a star’s life,” says Göran Pilbratt, ESA’s Herschel project scientist.

“Herschel offered the perfect observing capabilities to detect this extraordinary laser in the Ant Nebula. The findings will help constrain the conditions under which this phenomenon occurs and help us to refine our models of stellar evolution. It is also a happy conclusion that the Herschel mission was able to connect together Menzel’s two discoveries from almost a century ago.”

For more information, visit http://www.esa.int/Our_Activities/Space_Science/Herschel/A_space_ant_fires_its_lasers.

The Lunar and Planetary Institute's 50th Anniversary Science Symposium

Commemorating 50 Years of Planetary Science at the Lunar and Planetary Institute

The Lunar and Planetary Institute (LPI), established in 1968, is devoted to the study of the formation of the solar system, its evolution into the dynamic planetary system we have today, and the potential for life elsewhere.

To commemorate the LPI's 50th anniversary, a one-day science symposium was held on March 17, 2018, in the Lecture Hall of the Universities Space Research Association building in Houston, Texas. The symposium program was organized starting with the inner planets extending to the outer solar system and beyond. The talks were presented by leaders in the planetary science community, many of whom were former LPI scientists and interns.

In this issue we highlight Dr. Tracy Gregg (SUNY Buffalo), a former LPI intern, who presented *Exploring Eruptions in the Solar System: 50 Years and 256 Shades of Gray*.

Watch video here.

Meeting Highlights

Mercury: Current and Future Science of the Innermost Planet

In May 2018, the international Mercury science community gathered in Columbia, Maryland, for the Mercury: Current and Future Science of the Innermost Planet meeting. In total, 123 scientists from 12 countries participated in the meeting, with 41% of the participants traveling from outside the United States to attend. The meeting focused on all scientific aspects of the planet Mercury, including both the current state of knowledge and the prospects for future endeavors. One of the major take-home messages from the meeting was that there is a sizable, active, and energetic international Mercury science community, and getting this community together for this meeting and in the future is productive and important.

One of the main reasons that there now exists a strong Mercury science community is because of the success of NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission. MESSENGER provided a wealth of data about Mercury, and these data were the focus of many of the meeting's presentations and discussions. Results from the MESSENGER mission have also motivated new experimental and modeling research, to interpret Mercury's history and the processes that have acted on the planet in the past as well as those that continue to act in the present day. Ongoing observations from Earth-based telescopes were also presented, which further advance our understanding of Mercury's surface, exosphere, and dynamical environment and enable studies of Mercury on longer timescales than any single mission.

Additionally, the Mercury science community is strong because the future spacecraft exploration of Mercury is set to continue. The joint ESA-JAXA BepiColombo mission is scheduled to launch in October 2018, and to arrive at Mercury in 2025. BepiColombo will be the first mission to deliver two spacecraft into orbit about Mercury, the Mercury Planetary Orbiter and the Mercury Magnetospheric Orbiter. The meeting included many discussions about BepiColombo's plans, and the community expressed excitement and anticipation for the new measurements and potential new discoveries.

The three-day meeting was packed with diverse Mercury science topics from the 129 abstracts associated with the meeting. The oral sessions ranged from Mercury's exosphere and magnetosphere, to the planet's surface geology and composition, to the geophysical and geochemical structure of Mercury's deep interior. A poster session with a reception was held on the first evening, with 33 posters making for lively discussions. E-posters are available on the meeting website from those participants who chose to make them available. One of the meeting participants, Emily Lakdawalla of The Planetary Society, wrote a wonderful story that highlights some of the scientific results presented at the meeting: http://www.planetary.org/blogs/emily-lakdawalla/2018/0517-mercury2018-from-messenger.html.

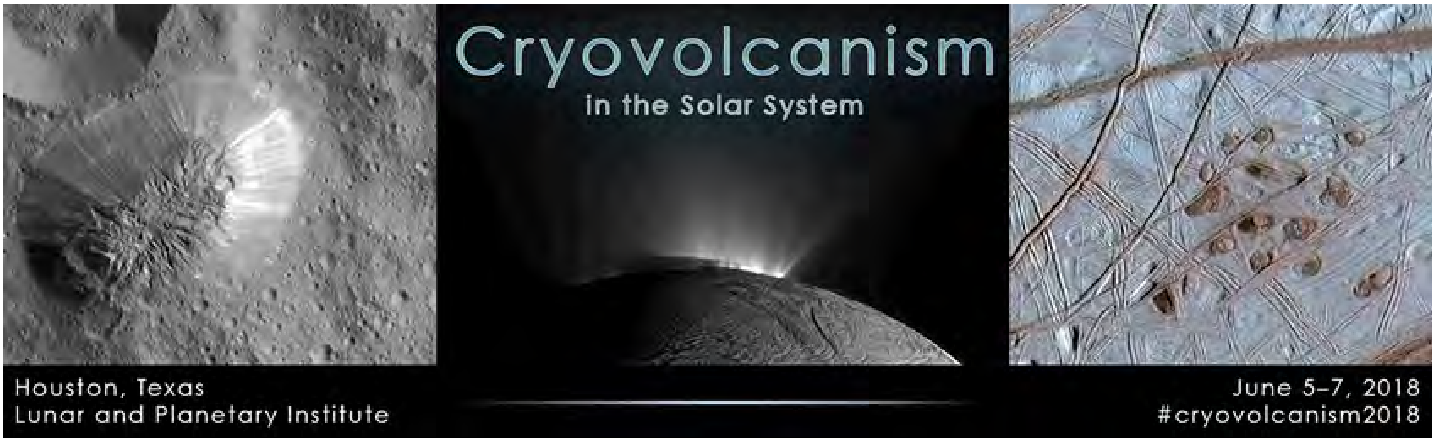
Between the presentations of Mercury science results and BepiColombo plans, one two-hour session of the meeting was devoted to discussions for the future exploration of Mercury, beyond BepiColombo. The session included presentations about efforts related to the last U.S. National Academies Planetary Science Decadal Survey, including an engineering study of a possible Mercury lander. Short presentations followed where scientists laid out some of the top-priority science questions that could drive the future exploration of Mercury. The session ended with a discussion of what the Mercury community should do going forward, to keep the community strong and to keep Mercury as a compelling option for future missions. Along with continuing special Mercury-focused sessions at planetary science meetings, there was a strong sentiment that meetings like the current one should occur in the future. Happily, plans are already underway in setting the dates and location for the Mercury 2020 meeting!

The discussion also showed that there is strong support for the importance of future Mercury exploration missions beyond BepiColombo. At the meeting, a poster was hung to enable community members to brainstorm possible future Mercury exploration ideas and to sign up to be involved in future efforts. In total, 74 individuals signed up, demonstrating the strong support for the future exploration of Mercury. Possible next steps for the Mercury community that were mentioned included writing white papers and forming a group similar to the Analysis or Assessment Groups that other planetary science communities have, such as SBAG, OPAG, VEXAG, MEPAG, and LEAG. Mercury currently does not fit within any of these existing analysis groups. Interestingly, discussions subsequent to the meeting revealed that NASA's Planetary Science Advisory Committee discussed the need for a Mercury analysis group at their February 2018 meeting and drafted a finding to support the formation of such a group. It will be important to see how all of this strong interest and support for future Mercury exploration develops over the next few months.

Overall, the Mercury 2018 meeting was a great success and is positioned to be the first in a regularly occurring series. It was encouraging that among the meeting participants there were 23 students, and it was greatly appreciated that LPI was able to provide 10 early career scientists with travel support awards. The meeting was highly productive but also showed that there is still much to be answered about Mercury, through continued research with MESSENGER and other datasets, through BepiColombo's unprecedented two spacecraft measurements, and through future exploration of our solar system's innermost planet.

For more information, and to view the program and abstracts, visit the workshop website athttps://www.hou.usra.edu/meetings/mercury2018/.

Cryovolcanism in the Solar System



The Cryovolcanism in the Solar System workshop was held at the Lunar and Planetary Institute in Houston, Texas, on June 5–7, 2018. This workshop brought together attendees to better understand the past, present, and future of cryovolcanic research.

The two-and-a-half-day workshop covered background on cryovolcanism to 41 attendees. Overview talks included topics on how silicate volcanism helps to inform cryovolcanic processes and what kinds of features have been hypothesized to be cryovolcanic in origin. Subsequent presentations reviewed cryovolcanic features on bodies in the solar system, including the unique brine-driven volcanism on the dwarf planet Ceres. Talks combined active research areas like Pluto's Wright Mons, which is hypothesized to be a cryovolcano, as well as discussing the mechanics of how to drive negatively buoyant materials onto the surface of icy bodies through their icy crusts.

The workshop allotted significant blocks of time to encourage time for discussion, and by the end of the meeting participants suggested that this become a reoccurring workshop with a cadence of 2–3 years. As more attention is drawn to ocean worlds, the increasing interest in refining our understanding of cryovolcanic processes has grown. We anticipate organizing a follow-up workshop in the next few years.

For more information, including links to the program and abstracts, visit the meeting website at https://www.hou.usra.edu/meetings/cryovolcanism2018/.

Spotlight on Education

Upcoming Public Event Opportunities

Upcoming opportunities exist for public engagement around the broader topics of NASA planetary exploration. Consider getting in touch with local astronomical societies, planetariums and museums, local scientists, and NASA's Solar System Ambassadors (solarsystem.nasa.gov/ssa/directory.cfm) and ask them to join your events and share their experiences or resources with your audience. Tips for scientists in conducting public engagement are at www.lpi.usra.edu/education/scientist-engagement.

Mars Opposition

Mars at Opposition, 27 July 2018, 10:00 p.m. Central Daylight Time

Planetary oppositions provide opportunities for great telescopic viewing. Throughout summer 2018, the oppositions of Mars, Jupiter, and Saturn will make these planets ideal for telescopic viewing: https://in-the-sky.org/news.php?id=20180727_12_100

Perseid Meteor Shower

August 12-13, 2018

The 2018 Perseid meteor shower will peak the night of August 12-13. The Perseid meteors are made of pieces from comet Swift-Tuttle and appear to originate from the constellation Perseus, hence their name. Learn more about the Perseids at https://solarsystem.nasa.gov/small-bodies/meteors-and- meteorites/perseids/in-depth/.

OSIRIS-REx Begins Approach Phase to Asteroid Bennu

August 17, 2018

On August 17, OSIRIS-REx will see Bennu for the first time from a distance of approximately two million kilometers, and Science Operations will officially begin. Learn more at https://www.asteroidmission.org.

NASA: 60 Years and Counting

From 2018 through 2022, NASA is marking a series of important milestones including the 60^{th} anniversary of the agency's founding. Learn more at https://www.nasa.gov/60.

Resources for Planetary Scientists Interested in Public Engagement

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

AGU Education Session: Scientist and Engineer Partnerships in Education and Public Engagement (ED049)

Scientists and engineers conducting education and/or outreach activities are invited to submit an abstract to the Scientist and Engineer Partnerships in Education and Public Engagement session at the 2018 AGU Fall Meeting. Abstracts that share tools, resources, and lessons learned from your endeavors to engage your audiences are encouraged. Education, public engagement, and communication professionals are also welcome to submit abstracts to share best practices for helping to improve the impacts and outcomes of activities involving subject matter experts.

Abstracts deadline: August 1, 2018

Don't forget: submitting an education abstract won't count against your first author science abstract submissions! At AGU, one first author education abstract is allowable in addition to a science abstract.

Questions? Contact Andy Shaner (shaner@lpi.usra.edu) or Sanlyn Buxner (buxner@psi.edu).

More information: https://agu.confex.com/agu/fm18/prelim.cgi/Session/52689

AGU First Author Policy: https://fallmeeting.agu.org/2018/abstract-submissions/author-policy

AGU Opens 2018 Data Visualization and Storytelling Competition

Students, get your data ready and polish your storytelling skills for AGU's Data Visualization and Storytelling Competition. Show us how you can creatively present data pertaining to the Earth, solar system, and universe. Winners receive the opportunity to present their visually based story on the NASA Hyperwall, as well as travel grants and complimentary registration to the fall meeting. This competition is limited to students who are legal U.S. residents and enrolled full time in a 2- or 4-year undergraduate or graduate institution in the United States.

Application deadline: August 31, 2018

Competition URL: https://education.agu.org/grants/data-visualization-storytelling-competition/award-information/

ASP Annual Meeting: Advancing Astronomy for All

ASP Annual Meeting: Advancing Astronomy for All
September 10 – 13, 2018

The ASP's 130th Annual Meeting is a broad science education/outreach conference featuring plenary talks/panels, contributed workshops/sessions, and oral/poster presentations addressing a wide range of professional work, research, and evaluation in education, communication, and diversity in science. Visit www.astrosociety.org/about-us/asp-annual-meetings/asp-2018-annual-meeting for more information.

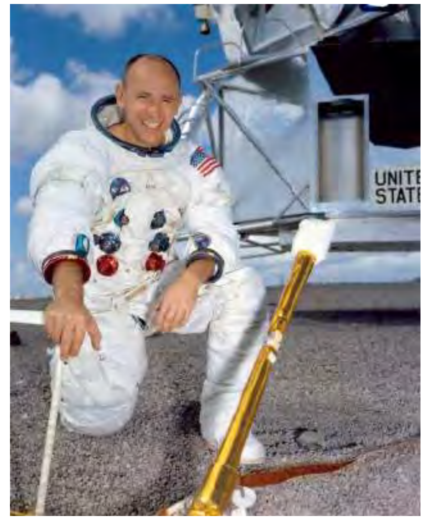
NASA Postdoctoral Program Fellowships

NASA Postdoctoral Program Fellowships
npp.usra.edu

The NASA Postdoctoral Program, or NPP, supports NASA's goal to expand scientific understanding of the Earth and the universe in which we live. Selected by a competitive peer-review process, NPP fellows complete one- to three-year fellowships that offer scientists and engineers unique opportunities to conduct research in fields of science relevant to NASA. These opportunities advance NASA's missions in earth science, heliophysics, planetary science, astrophysics, space bioscience, aeronautics and engineering, human exploration and space operations, and astrobiology. Opportunities are available at NASA centers and other NASA-approved sites. Interested applicants may apply by one of three annual application deadlines: March 1, July 1, and November 1.

In Memoriam

Alan L. Bean, 1932–2018



Alan LaVern Bean, the fourth human to walk on the Moon, and an accomplished artist, passed away on Saturday, May 26, at the age of 86.

A test pilot in the U.S. Navy, Bean was one of 14 trainees selected by NASA for its third group of astronauts in October 1963. He flew twice into space, first as the lunar module pilot on Apollo 12, the second Moon landing mission, in November 1969, and then as commander of the second crewed flight to the United States' first space station, Skylab, in July 1973.

On November 19, 1969, Bean, with Apollo 12 commander Charles "Pete" Conrad, landed on the Ocean of Storms and became the fourth human to walk on the Moon. During two moonwalks, Bean helped deploy several surface experiments and installed the first nuclear-powered generator station on the Moon to provide the power source. He and Conrad inspected a robotic Surveyor spacecraft and collected 34 kilograms (75 pounds) of rocks and lunar soil for study back on Earth.

"Alan and Pete were extremely engaged in the planning for their exploration of the Surveyor III landing site in the Ocean of Storms and, particularly, in the enhanced field training activity that came with the success of Apollo 11. This commitment paid off with Alan's and Pete's collection of a fantastic suite of lunar samples, a scientific gift that keeps on giving today and in the future," said Harrison Schmitt, Apollo 17 lunar module pilot and the only geologist to walk on the Moon. "Their description of bright green concentrations of olivine (peridot) as 'ginger ale bottle glass,' however, gave geologists in Mission Control all a big laugh, as we knew exactly what they had discovered."

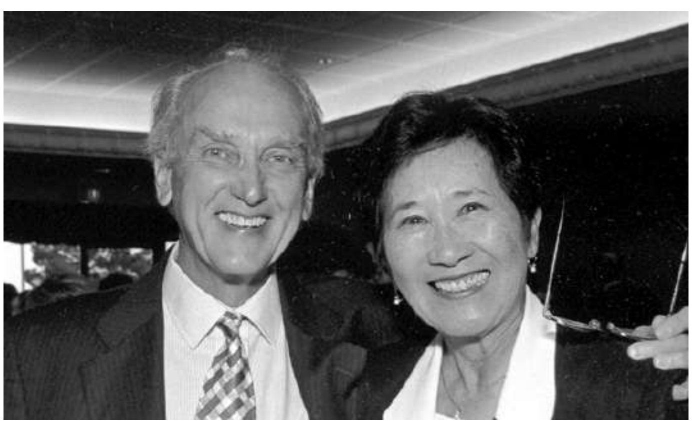
"When Alan's third career as the artist of Apollo moved forward, he would call me to ask about some detail about lunar soil, color or equipment he wanted to have represented exactly in a painting. Other times, he wanted to discuss items in the description he was writing to go with a painting. His enthusiasm about space and art never waned. Alan Bean is one of the great renaissance men of his generation — engineer, fighter pilot, astronaut and artist," said Schmitt.

Four years after Apollo 12, Bean commanded the second crew to live and work onboard the Skylab orbital workshop. During the then-record-setting 59-day flight, Bean and his two crewmates generated 29 kilometers (18 miles) of computer tape during surveys of Earth's resources and 76,000 photographs of the Sun to help scientists better understand its effects on the solar system.

In total, Bean logged 69 days, 15 hours, and 45 minutes in space, including 31 hours and 31 minutes on the Moon's surface.

Bean retired from the Navy in 1975 and NASA in 1981. In the four decades since, he devoted his time to creating an artistic record of humanity's first exploration of another world. His Apollo-themed paintings featured canvases textured with lunar bootprints and were made using acrylics embedded with small pieces of his Moon-dust-stained mission patches.

Michael J. S. Belton, 1934–2018



Michael J.S. Belton, the President of Belton Space Exploration Initiatives and an Emeritus Astronomer at the National Optical Astronomy Observatory (NOAO), passed away on Monday, June 4, 2018. He was a member of the Planetary Science Institute (PSI) Board of Trustees. Born in Bognor Regis, England, he received his Bachelor's degree at the University of St. Andrews in Scotland, and earned his Ph.D. at the University of California, Berkeley. He joined Kitt Peak National Observatory (the precursor to NOAO) in 1964 and carried out research on nearly all objects that fell under planetary science.

Belton was a member of the Mariner 10 team that flew a space probe by Mercury and Venus. As a member of the Mariner Jupiter/Uranus Science Advisory Committee, he helped define what became the Voyager missions to the outer solar system. He was the Leader of the Galileo Mission Imaging Science Team. Galileo studied the Earth's Moon, made the first close-up observations of an asteroid, Gaspra, and discovered the first moon of an asteroid, Dactyl, as it passed the asteroid Ida on its way to Jupiter. Before arriving, the team observed the impact of the fragments of Comet Shoemaker-Levy 9 into the Jupiter atmosphere and later studied the aftermath in detail. At Jupiter, Belton and his team delved into the nature of the Galilean satellites, the population of small satellites, the jovian ring system, and the planet's atmosphere.

He was particularly interested in the origin and evolution of planetary systems, the physics of planetary atmospheres, high-resolution groundbased spectroscopy, and had a special affinity for comets. He studied them from ground- and spacebased telescopes and missions. His contributions were focused on understanding the mechanisms of cometary outbursts, determination of rotational states, exploring the interiors of cometary nuclei, how cometary activity can be used to probe the nucleus, and the size distribution of comets. Belton was also a leader of the planetary science community, most notably chairing the first National Research Council Decadal Survey of Solar System Exploration.

For his contributions to the exploration of the solar system, an asteroid was designated 3498 Belton by the International Astronomical Union, and in 1995 the Division for Planetary Sciences of the American Astronomical Society awarded him the Gerard P. Kuiper Prize.

In 2000, he founded Belton Space Exploration Initiatives, LLC.

Among the young astronomers who worked with him on his many projects, Belton was a mentor who unselfishly encouraged their professional growth. He was an engaging, interested, and positive colleague. He was an out-of-the box thinker and visionary in the truest sense.

Bradford A. Smith, 1931–2018

Bradford A. Smith, a pioneer in the exploration of the solar system, passed away on Tuesday, July 3, 2018. During his career, Smith participated in a number of U.S. and international space missions, including Mars Mariners 6 and 7, the Mars Viking mission, the Soviet Vega mission to Halley's Comet, the Soviet Phobos mission to Mars, and the Wide Field/Planetary Camera team for the Hubble Space Telescope. He was the deputy team leader of the imaging team on the Mariner 9 Mars Orbiter, and was chosen by NASA to lead the camera team on the Voyager missions to Jupiter, Saturn, Uranus, and Neptune. He co-discovered a circumstellar disk around the nearby star, Beta Pictoris, the first direct evidence of a planetary system beyond our own, and continued these studies as a member of the infrared camera (NICMOS) experiment on the Hubble Space Telescope.

Smith spent two years in the military as an astronomer with the U.S. Army Map Service working at the White Sands Missile Range in New Mexico, where he began a long and productive association with Clyde Tombaugh. Together, Smith and Tombaugh carried out a search for possible natural satellites of the Moon at Lowell Observatory during the lunar eclipse of November 17–18, 1956 (none was found), and soon afterward Smith followed Tombaugh to New Mexico State University, where he served as Associate Professor of Astronomy.

At NMSU he established a program of systematic planetary photography in 1958, and initiated a program of high-resolution, groundbased observations of the planets in support of Mariner, Viking, and Voyager missions that NASA would fund for the next 30 years.

In 1974, Smith was recruited to the Lunar and Planetary Laboratory at the University of Arizona with joint appointments as Professor in Planetary Sciences and Astronomy at the University of Arizona, as Research Astronomer at the Institute for Astronomy at the University of Hawaii at Manoa, and as a Visiting Associate in the Division of Geological and Planetary Sciences at the California Institute of Technology. In early 1976, Smith and his co-workers were the first to use a CCD detector on an astronomical telescope, yielding the first high-resolution infrared images of Uranus and Neptune.

Smith was awarded the NASA Medal for Exceptional Scientific Achievement four times, and asteroid 8553 (bradsmith) is named for him. Smith served as the president of IAU Commission 16 for the physical studies of planets and satellites and as a member of the IAU Working Group for Planetary System Nomenclature. He was a co-author on four editions of *21st Century Astronomy* and two editions of *Understanding our Universe*. He also coauthored with Stephen E. Strom the book *Earth & Mars: A Reflection*, published by the University of Arizona Press. He published popular articles in *National Geographic Magazine* and *Sky and Telescope*. Most recently, he was one of the team members featured in a full-length film,*The Farthest*, which chronicled the Voyager mission, calling it "one of the greatest feats of exploration our species has ever undertaken."

NASA Announces New Director of Johnson Space Center

NASA Administrator Jim Bridenstine announced the selection of Mark Geyer as the next director of the agency's Johnson Space Center in Houston. He assumed the director's position on May 25, when current Center Director and former astronaut, Ellen Ochoa, retired after 30 years at the agency.

As Johnson's center director, he'll lead one of NASA's largest installations, which has about 10,000 civil service and contractor employees — including those at White Sands Test Facility in Las Cruces, New Mexico — and oversee a broad range of human spaceflight activities.

Geyer served as the acting deputy associate administrator for Technical for the Human Explorations and Operations Mission Directorate at NASA Headquarters in Washington. In that position, which he assumed October 1, 2017, he was responsible for assisting the associate administrator in providing strategic direction for all aspects of NASA's human spaceflight exploration mission. Before that, Geyer served as deputy center director at Johnson until September 2017.

Steve Jurczyk Appointed NASA Associate Administrator; Krista Paquin Retires; Melanie W. Saunders Named Acting Deputy Associate Administrator

NASA Administrator Jim Bridenstine named Steve Jurczyk as associate administrator, the agency's highest-ranking civil servant position. Jurczyk has been serving in the position in an acting capacity since March 10. In addition, Deputy Associate Administrator Krista Paquin will retire from NASA at the end of May. Melanie W. Saunders has been assigned as the acting deputy associate administrator, effective June 10.

Until his appointment as associate administrator, Jurczyk had been associate administrator of the Space Technology Mission Directorate since June 2015. In this position, he formulated and executed the agency's space technology programs, focusing on developing and demonstrating transformative technologies for human and robotic exploration of the solar system in partnership with industry and academia.

Previously, he was director at NASA's Langley Research Center in Hampton, Virginia. Named to this position in May 2014, he headed NASA's first center, which plays a critical role in NASA's aeronautics research, exploration and science missions. Jurczyk served as Langley's deputy center director from August 2006 until his appointment as director.

Jurczyk began his NASA career in 1988 at Langley in the Electronic Systems Branch as a design and integration and test engineer developing several space-based Earth remote sensing systems. From 2002 to 2004, Jurczyk was director of engineering, and from 2004 to 2006 he was director of research and technology at Langley, where he led the organizations' contributions to a broad range of research, technology, and engineering disciplines contributing to all NASA mission areas.

He has received many awards during his career, including two NASA Outstanding Leadership Medals, the Presidential Rank Award for Meritorious Executive in 2006, and the Presidential Rank Award for Distinguished Executive in 2016 — the highest honors attainable for federal government leadership. He is an associate fellow of the American Institute of Aeronautics and Astronautics, and a graduate of the University of Virginia, where he received a Bachelor of Science and a Master of Science in Electrical Engineering in 1984 and 1986.

In an agency career spanning more than 30 years, Paquin has served in many critical roles. She started at NASA in 1984 as a Presidential Management Intern, and spent 22 years of her career at the Goddard Space Flight Center in Greenbelt, Maryland. As a senior executive at Goddard, she was assigned the roles of associate director of management operations, deputy director of the Applied Engineering and Technology Directorate, deputy director for Planning and Business Management of Flight Programs, and Goddard associate center director.

In her latest role as deputy associate administrator at Headquarters, she chairs the NASA Mission Support Council, which serves as the senior decision-making body regarding the integrated agency mission support portfolio. Paquin also was associate administrator for the Mission Support Directorate from April 2015, where she was responsible for the leadership and integration of NASA mission support functions with an annual budget of more than $3 billion. She oversaw agencywide human capital management, strategic infrastructure, procurement, protective services, audit liaison, agency directives management, NASA Headquarters operations, the NASA Shared Services Center and NASA partnerships, including Space Act Agreements.

Appointed to the Senior Executive Service (SES) in 1999, Paquin was the recipient of numerous awards, including NASA's Distinguished Service Medal, the SES Presidential Rank Award for Meritorious Executive, and the NASA Outstanding Leadership Medal. She holds bachelors and masters degrees in Urban Planning and Management from the University of Maryland.

Saunders has been acting deputy center director at the Johnson Space Center in Houston since February 1, where she helps to manage one of NASA's largest installations, with almost 10,000 civil service and contractor employees — including those at White Sands Test Facility in Las Cruces, New Mexico — and an annual budget of approximately $5 billion. Previously, she was Johnson's associate director and oversaw a broad range of human spaceflight activities.

Prior to being named associate center director, Saunders served as associate manager of the International Space Station Program from 2005 to 2009, during the most intensive phases of space station assembly. From 2003 to 2005, she was deputy manager of the station's External Relations Office. Saunders began her NASA career in 1994 as the manager for International Policies for the International Space Station Program, where she negotiated international agreements.

During her NASA career, Saunders has been recognized with the Meritorious Presidential Rank Award, two NASA Outstanding Leadership Medals, the NASA Exceptional Service Medal, a Silver Snoopy, and numerous other individual and group achievement awards. She also was profiled in the inaugural edition of Women@NASA, and in Summer 2017 was featured in Profiles in Diversity, Women Worth Watching. She holds a bachelor's degree in history from the University of California, Santa Barbara and a Juris Doctorate from the University of California, Davis.

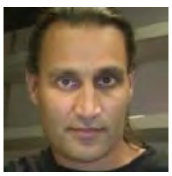
National Academy of Sciences Members and Foreign Associates Elected

The National Academy of Sciences (NAS) announced the election of 84 new members and 21 foreign associates in recognition of their distinguished and continuing achievements in original research.

Those elected bring the total number of active members to 2,382 and the total number of foreign associates to 484. Foreign associates are nonvoting members of the Academy, with citizenship outside the United States.

Two members of the planetary science community were elected into the NAS:

James F. Kasting



Michael Manga

Kasting, James F.: Evan Pugh Professor, department of geosciences, Pennsylvania State University, University Park

Manga, Michael: professor of earth and planetary sciences, department of earth and planetary science, University of California, Berkeley

For the full listing of those elected, visit http://www.nasonline.org/news-and-multimedia/news/May-1-2018-NAS-Election.html.

SSERVI 2018 Exploration Science Forum Awards

Recognizing that science and exploration go hand in hand, NASA created SSERVI in 2013, expanding the scope of the former NASA Lunar Science Institute to include basic and applied scientific research on the Moon, near Earth asteroids, and the Martian moons Phobos and Deimos. The Eugene Shoemaker Distinguished Scientist medal, Michael J. Wargo Award, Susan Mahan Niebur Award, and Angioletta Coradini Award recognize outstanding achievements in exploration science. The winners are nominated by their academic peers and are selected by the Solar System Exploration Research Virtual Institute (SSERVI) Director, Dr. Yvonne Pendleton. The awards were presented along with invited lectures from the recipients at the 2018 Exploration Science Forum (ESF) which took place June 26-28 at the NASA Ames Research Center in Moffett Field, California.

EUGENE SHOEMAKER DISTINGUISHED SCIENTIST MEDAL

The 2018 Eugene Shoemaker Distinguished Scientist Medal, named after American geologist and one of the founders of planetary science, Eugene Shoemaker (1928-1997), is awarded to Dr. M. Darby Dyar of the Planetary Science Institute and Mt. Holyoke College for her significant scientific contributions throughout the course of her career. The award includes a certificate and medal with the Shakespearian quote "And he will make the face of heaven so fine, that all the world will be in love with night."

Dr. Dyar has had a distinguished career spanning more than 30 years in which she authored 242 peer-reviewed publications. Darby's expertise are numerous, including optical mineralogy, crystal chemistry, and numerous spectroscopic techniques. In recent years she has also revolutionized the use of machine learning techniques in the analysis and interpretation of X-ray absorption spectra. The careful laboratory work and model development that she has led throughout her career have enabled thousands of other papers that have used the data she has generated; her work will prove to be substantially more important than any single mission. Without Dr. Dyar in our field for the last 30 years, our understanding of planetary processes and the interpretation of various mission data would be much poorer.

MICHAEL J. WARGO EXPLORATION SCIENCE AWARD

The Michael J. Wargo Exploration Science Award is an annual award given to a scientist or engineer who has significantly contributed to the integration of exploration and planetary science throughout their career. Dr. Michael Wargo (1951-2013) was Chief Exploration Scientist for NASA's Human Exploration and Operations Mission Directorate and was a strong advocate for the integration of science, engineering and technology. The 2018 Michael J. Wargo Exploration Science Award is given to Dr. David Kring at the Lunar and Planetary Institute in Houston, Texas.

Dr. Kring's research explores the origin of the solar nebula and its evolution into a geologically active planetary system; the geologic history of the Earth, Moon, Mars, and several smaller planetary bodies; impact cratering on the Earth, its effect on Earth's environment, and its possible role in the biological evolution of our planet; and the chemical and physical properties of meteorites. He is currently integrating his field experience in impact-cratered terrains with his analytical experience of Apollo, Luna, and lunar meteorite sample collections from the Moon to lead the development of spacecraft missions in response to the President's lunar exploration initiative.

SUSAN MAHAN NIEBUR EARLY CAREER AWARD

The 2018 Susan Mahan Niebur Early Career Award is an annual award given to an early career scientist who has made significant contributions to the science or exploration communities. Recipients of the Susan M. Niebur Early Career Award are researchers who are no more than ten years from receiving their PhD, who have shown excellence in their field and demonstrated meaningful contributions to the science or exploration communities. Susan Mahan Niebur (1978-2012) was a former Discovery Program Scientist at NASA who initiated the first ever Early Career Fellowship and the annual Early Career Workshop to help new planetary scientists break into the field. This year the prize is presented to Dr. Rachel Klima at the Johns Hopkins University Applied Physics Laboratory.

Dr. Klima is one of the premiere airless body spectroscopists of her generation, with published papers about the Moon, Mercury, Vesta, and other asteroids. Her general expertise in spectroscopy and lunar data has led her to lead and participate in studies of other materials as well, most notably lunar water and hydroxyl. Outside published papers, her knowledge has put her in great demand — she has been sought after to play important roles in proposed missions. Currently, she serves as a member of the project science team for the Europa Clipper mission. She has won a Carl Sagan Early Career Fellowship from NASA, showing that her promise has been widely recognized.

ANGIOLETTA CORADINI MID-CAREER AWARD

The SSERVI Angioletta Coradini Mid-Career Award is given annually to a mid-career scientist for broad, lasting accomplishments related to SSERVI fields of interest. Angioletta Coradini (1946-2011) was an Italian planetary scientist who has inspired astronomers around the world. The 2018 Angioletta Coradini Mid-Career Award is given to Dr. Barbara Cohen at NASA Goddard Space Flight Center.

Dr. Cohen's main scientific interests are in geochronology and geochemistry of planetary samples from the Moon, Mars and asteroids. She is a Principal Investigator on multiple NASA research projects, a member of the Mars Exploration Rover mission team still operating the Opportunity rover, and the principal investigator for Lunar Flashlight, a lunar cubesat mission that will be launched in 2018. She has participated in the Antarctic Search for Meteorites (ANSMET) over three seasons, where she helped recovered more than a thousand pristine samples for the U.S. collection, and asteroid 6186 Barbcohen is named for her.

More information on these awards and recipients, along with past awardees, can be found at: https://sservi.nasa.gov/awards.

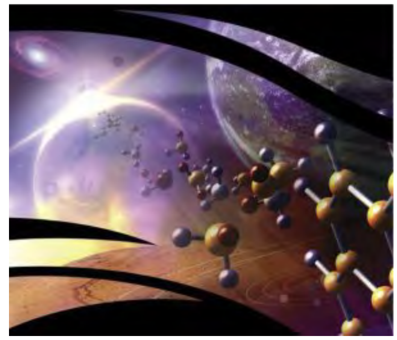
Barringer Award Recipients Announced

The Lunar and Planetary Institute announced the names of the students whose research will be supported by The Barringer Family Fund for Meteorite Impact Research. The 2018 awardees are Neeraja Chinchalkar (Auburn University, United States), Thomas Déhais (Vrije Universiteit Brussel, Belgium), Sietze de Graaff (Vrije Universiteit Brussel, Belgium), and Elycheikh Mohamed Naviee (Hassan II University of Casablanca, Morocco).

The Barringer Family Fund for Meteorite Impact Research was established to support field work by eligible students interested in the study of impact cratering processes. The Fund provides a small number of competitive grants each year for support of field research at known or suspected impact sites worldwide. In addition to its memorial nature, the Fund also reflects the family's long-standing commitment to responsible stewardship of The Barringer Meteorite Crater and the family's steadfast resolve in maintaining the crater as a unique scientific research and education site.

For more information, visit: The Barringer Family Fund for Meteorite Impact Research.

NASA Awards Grants for Research into Life in Universe



NASA has awarded five-year grants, each approximately $8 million, to three research teams that will study the origins, evolution, distribution and future of life in the universe.

"With NASA's Transiting Exoplanet Survey Satellite on its way to discover new worlds around our nearest stellar neighbors, Cassini's discovery of the ingredients necessary for life in Enceladus' plumes, and with Europa Clipper and Mars 2020 on the horizon, these research teams will provide the critical interdisciplinary expertise needed to help interpret data from these missions and future astrobiology-focused missions," said NASA Chief Scientist Jim Green.

The interdisciplinary teams will become members of the NASA Astrobiology Institute (NAI), headquartered at the agency's Ames Research Center in Silicon Valley, California. The NAI serves a vital role in advancing the goals of the NASA Astrobiology Program, with a focus on seeking the answers to these fundamental questions: How does life begin and evolve? Is there life beyond Earth, and if so, how can we detect it? What is the future of life on Earth and beyond?

The selected teams are:

Evolution of Nanomachines in Geospheres and Microbial Ancestors (ENIGMA)

Rutgers University
New Brunswick, New Jersey

Led by Professor Paul Falkowski, the ENIGMA team will investigate how proteins evolved to become the catalysts of life on Earth by looking at prebiotic molecules and enzymes that are ancestral and common across many types of microbes.

The Astrobiology Center for Isotopologue Research (ACIR)

Pennsylvania State University, University Park

ACIR, led by Professor Kate Freeman, will address how the features of elements within molecules reveal the origins and history of organic compounds, from compounds that arrived from planetary environments to those that were derived from metabolic systems, using cutting-edge observational and computational tools.

NASA's Jet Propulsion Laboratory (JPL)

Pasadena, California

Dr. Rosaly Lopes will lead research at JPL focusing on Saturn's largest moon, Titan, to address what habitable environments may exist on the moon and what potential signatures of life would be expected, using data from the Cassini-Huygens mission. These data cover a wide swath of the moon, from beneath its surface all the way up through its thick atmosphere.

NASA Selects Three Informal Learning Institutions to Inspire Next Generation

NASA's Teams Engaging Affiliated Museums and Informal Institutions (TEAM II) has selected three informal education organizations to promote science, technology, engineering and math (STEM) learning to inspire the next generation of explorers.

The TEAM II solicitation of approximately $2 million will be awarded to the selected projects from the organizations:

- The Moon and Beyond: An Immersive Game for STEM Learning in Museums and Planetariums, Arizona Science Center, Phoenix
- Growing Beyond Earth Innovation Studio, Fairchild Tropical Botanic Garden Inc., Coral Gables, Florida
- Apollo Redux: Inspiring Next Generations of Engineers and Scientists through use of Historic Mission Operation Control Room Consoles and Simfault Interactive Programs, Kansas Cosmosphere and Space Center Inc., Hutchinson, Kansas

The selected projects provide authentic mission-driven STEM experiences that include a new immersive escape room-inspired STEM game; traveling exhibitions featuring actual Apollo Mission Control Room consoles and interactive mission simulations; and the world's first makerspace in a botanic garden, dedicated to NASA's food production challenges.

The projects, selected from 43 proposals through a peer reviewed process, will be implemented over the next two to three years. The projects range in value from approximately $650,000 to $750,000.

For more information on 2018 NASA TEAM II, visit: https://go.nasa.gov/2J8AKqK.

For more information on NASA's education programs, visit: http://www.nasa.gov/education.

Take a Virtual Trip to a Strange New World with NASA

On NASA's Exoplanet Exploration website, you can explore an imagined surface of an alien world via 360-degree, interactive visualizations. As you investigate each planet's surface, you'll discover fascinating features, like the blood-red sky of TRAPPIST-1d, or stand on a hypothetical moon of the massive planet Kepler-16b, which appears larger than either of the planet's two suns. The view from each planet's surface is an artist's impression based on the limited data that is available; no real photos of these planets exist.

The newest planet to feature this 360-degree surface visualization is Kepler-186f, an Earth-size planet orbiting a star much cooler and redder than the Sun. Scientists don't know if Kepler-186f has an atmosphere, but with the NASA visualization tool, you can see how the presence or absence of an atmosphere would change the view of the sky from the planet's surface.

All the 360-degree visualizations are viewable on desktop and mobile devices, or in virtual reality headsets that work with smartphones. You can also peruse travelposters of such distant worlds as Kepler 186f; TRAPPIST-1e, or PSO J318.5-22, where the "nightlife never ends" because the planet doesn't orbit a star, but is instead floating freely through space.

For even more information and visualizations of these alien worlds, check out NASA's Eyes on Exoplanets mobile app.

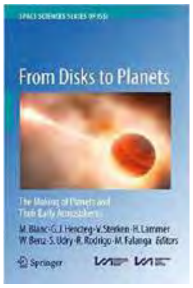
Visit NASA's Exoplanet Exploration website:

https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/

https://www.jpl.nasa.gov/news/news.php?feature=7140&utm_source=iContact&utm_medium=email&utm_campaign=NASAJPL&utm_content=exoplanet20180524-1

New and Noteworthy

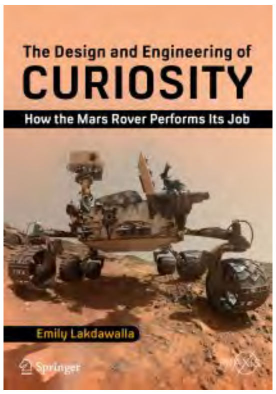
From Disks to Planets: The Making of Planets and Their Early Atmospheres



Springer, 2018, 372 pp., Hardcover. $139.99. www.springer.com

This volume discusses the evolutionary paths linking planets and their atmospheres to their origin within circumstellar disks. It reviews the main phases of this evolution, summarizes what we understand and what are the important open questions, and suggests ways toward solutions. Dust accretion within disks generates planet cores, while gas accretion on these cores leads to the diversity of their fluid envelopes. The formation of planetary proto-atmospheres and oceans is an essential product of planet formation. A fraction of the planets retain their primary proto-atmosphere, while others lose it and may form a "secondary" atmosphere. When the disk finally dissipates, it leaves us with the combination of a planetary system and a debris disk. Using the next generation of observing facilities, we will be able to reconstruct more accurately the evolutionary paths linking stellar genesis to the possible emergence of habitable worlds.

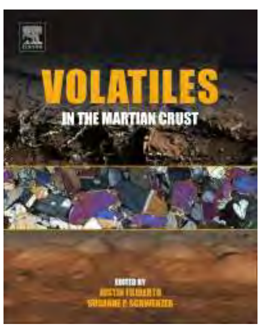
The Design and Engineering of Curiosity: How the Mars Rover Performs Its Job



Springer, 2018, 394 pp., Paperback. $39.99. www.springer.com

This book describes the most complex machine ever sent to another planet: Curiosity. It is a 1-ton robot with 2 brains, 17 cameras, 6 wheels, nuclear power, and a laser beam on its head. No one human understands how all of its systems and instruments work. This essential reference to the Curiosity mission explains the engineering behind every system on the rover, from its rocket-powered jetpack to its radioisotope thermoelectric generator to its fiendishly complex sample handling system. Its lavishly illustrated text explains how all the instruments work — its cameras, spectrometers, sample-cooking oven, and weather station — and describes the instruments' abilities and limitations. It tells you how the systems have functioned on Mars, and how scientists and engineers have worked around problems developed on a faraway planet: holey wheels and broken focus lasers. And it explains the grueling mission operations schedule that keeps the rover working day in and day out.

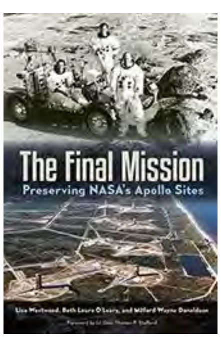
Volatiles in the Martian Crust



Elsevier, 2018, 432 pp., Hardcover, $99.95. www.elsevier.com

Volatiles in the Martian Crust is a vital reference for future missions — including ESA's EXO Mars and NASA's Mars2020 rover — looking for evidence of life on Mars and the potential for habitability and human exploration of the martian crust. Mars science is a rapidly evolving topic with new data returned from the planet on a daily basis. This book presents chapters written by well-established experts who currently focus on the topic, providing the reader with a fresh, up-to-date, and accurate view. Organized into two main sections, the first half of the book focuses on the martian meteorites and specific volatile elements. The second half of the book explores processes and locations on the crust, including what we have learned about volatile mobility in the martian crust. Coverage includes data from orbiter and *in situ* rovers and landers, geochemical and geophysical modeling, and combined data from the SNC meteorites.

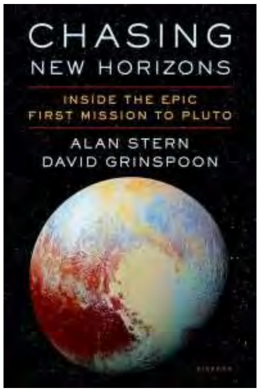
The Final Mission: Preserving NASA's Apollo Sites



University Press of Florida, 2018, 256 pp., Paperback. $24.95. upf.com

The world will always remember Neil Armstrong and Buzz Aldrin for their first steps on the Moon, yet few today hold in respect the sites that made these and other astronauts' journeys possible. Across the American landscape and on the lunar surface, many facilities and landing sites linked to the Apollo program remain unprotected. Some have already crumbled to ruins — silent and abandoned. *The Final Mission* explores these key locations, reframes the footprints and items left on the Moon as cultural resources, and calls for the urgent preservation of this space heritage. Beginning with the initiation of the space race, the authors trace the history of research, training, and manufacturing centers that contributed to lunar exploration. From the early rocket test stands of Robert H. Goddard, to astronaut instruction at Meteor Crater, to human and primate experiments at Holloman Air Force Base, innumerable places proved critical to developing the equipment for exploring space, surviving the journey, and returning to Earth safely. Despite their significance to the history of human spaceflight, many landmarks face the threat of damage or destruction. Most alarming is that the rapid advancement of technology renders stations obsolete long before they are deemed worthy of preservation. Moreover, the lack of precedence for protecting off-planet artifacts poses a unique challenge for space archaeology. While NASA's 2011 recommendations for spacefarers suggest avoiding close proximity to this cultural landscape, the authors advocate stronger routes of preservation and present models for safeguarding space history — both on Earth's surface and beyond.

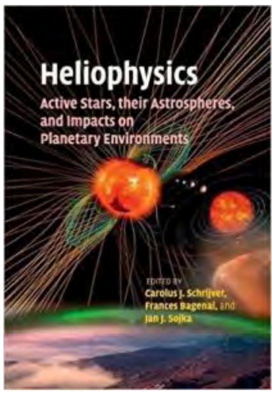
Chasing New Horizons: Inside the Epic First Mission to Pluto



Macmillan, 2018, 320 pp., Hardcover, $28.00. us.macmillan.com

On July 14, 2015, something amazing happened. More than 3 billion miles from Earth, a small NASA spacecraft called New Horizons screamed past Pluto at more than 32,000 miles per hour, focusing its instruments on the long mysterious icy worlds of the Pluto system, and then, just as quickly, continued on its journey out into the beyond. Nothing like this has occurred in a generation — a raw exploration of new worlds unparalleled since NASA's Voyager missions to Uranus and Neptune — and nothing quite like it is planned to happen ever again. The photos that New Horizons sent back to Earth graced the front pages of newspapers on all seven continents, and NASA's website for the mission received more than 2 billion hits in the days surrounding the flyby. At a time when so many think that our most historic achievements are in the past, the most distant planetary exploration ever attempted not only succeeded in 2015 but made history and captured the world's imagination. How did this happen? *Chasing New Horizons* is the story of the men and women behind this amazing mission: of their decades-long commitment and persistence; of the political fights within and outside NASA; of the sheer human ingenuity it took to design, build, and fly the mission; and of the plans for New Horizons' next encounter, 1 billion miles past Pluto in 2019. Told from the insider's perspective of mission leader Dr. Alan Stern and others on New Horizons, and including two stunning 16-page full-color inserts of images, *Chasing New Horizons* is a riveting account of scientific discovery, and of how much we humans can achieve when people focused on a dream work together toward their incredible goal.

Heliophysics: Active Stars, Their Atmospheres, and Impacts on Planetary Environments



Cambridge University Press, 2018, 405 pp., Paperback, $60.00.www.cambridge.org

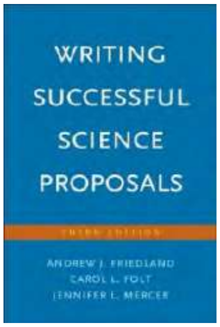
Heliophysics is a fast-developing scientific discipline that integrates studies of the Sun's variability, the surrounding heliosphere, and the environment and climate of planets. This volume, the fourth in the *Heliophysics* collection, explores what makes the conditions on Earth "just right" to sustain life, by comparing Earth to other solar system planets, by comparing solar magnetic activity to that of other stars, and by looking at the properties of evolving exoplanet systems. By taking an interdisciplinary approach and using comparative heliophysics, the authors illustrate how we can learn about our local cosmos by looking beyond it, and in doing so, also enable the converse. Supplementary online resources are provided, including lecture presentations, problem sets, and exercise labs, making this ideal as a textbook for advanced undergraduate- and graduate-level courses, as well as a foundational reference for researchers in the many subdisciplines of helio- and astrophysics.

Rocket Men: The Daring Odyssey of Apollo 8 and the Astronauts Who Made Man's First Journey to the Moon

Random House. 2018, 384 pp., Hardcover, $28.00. www.penguinrandomhouse.com

By August 1968, the American space program was in danger of failing in its two most important objectives: to land a man on the Moon by President Kennedy's end-of-decade deadline, and to triumph over the Soviets in space. With its back against the wall, NASA made an almost unimaginable leap: It would scrap its usual methodical approach and risk everything on a sudden launch, sending the first men in history to the Moon — in just four months. And it would all happen at Christmas. In a year of historic violence and discord — the Tet Offensive, the assassinations of Martin Luther King Jr. and Robert Kennedy, the riots at the Democratic National Convention in Chicago — the Apollo 8 mission would be the boldest, riskiest test of America's greatness under pressure. In this insider account, author Robert Kurson puts the focus on the three astronauts and their families: the commander, Frank Borman, a conflicted man on his final mission; idealistic Jim Lovell, who'd dreamed since boyhood of riding a rocket to the Moon; and Bill Anders, a young nuclear engineer and hotshot fighter pilot making his first space flight. Drawn from hundreds of hours of one-on-one interviews with the astronauts, their loved ones, NASA personnel, and myriad experts, and filled with vivid and unforgettable detail, *Rocket Men* is the definitive account of one of America's finest hours. In this real-life thriller, Kurson reveals the epic dangers involved, and the singular bravery it took, for mankind to leave Earth for the first time — and arrive at a new world.

Writing Successful Science Proposals, Third Edition



Yale University Press, 2018, 288 pp., Paperback, $22.00. yalebooks.yale.edu

This fully revised edition of the authoritative guide to science proposal writing is an essential tool for any researcher embarking on a grant or thesis application. In accessible steps, the authors detail every stage of proposal writing, from conceiving and designing a project to analyzing data, synthesizing results, estimating a budget, and addressing reviewer comments and resubmitting. This new edition is updated to address changes and developments over the past decade, including identifying opportunities and navigating the challenging proposal funding environment. The only how-to book of its kind, it includes exercises to help readers stay on track as they develop their grant proposals and is designed for those in the physical, life, environmental, biomedical, and social sciences, as well as engineering.

Sky & Telescope 15-Centimeter Globes

$24.99 each. 15-cm-diameter globe with stand. www.shoptatsky.com

Sky & Telescope has added to its globe family 15-centimeter (approximately 6-inch) spheres that portray Earth, the Moon, Mars, and Pluto. These smaller, more affordable globes are perfect for classroom use or for that special future astronaut in your life. Created with the same care and detail as their larger globes, these 15-centimeter globes look attractive on a desk and make a fine collection for your bookcase.

Margaret and the Moon: How Margaret Hamilton Saved the First Lunar Landing

Knopf Books for Young Readers, 2017, 40 pp., Hardcover. $17.99. Available on Amazon

Here's a true story from one of the Women of NASA! Margaret Hamilton loved numbers as a young girl. She knew how many miles it was to the Moon (and how many back). She loved studying algebra and geometry and calculus and using math to solve problems in the outside world. Soon math led her to the Massachusetts Institute of Technology (MIT), and then to helping NASA put a man on the Moon! She handwrote code that would allow the spacecraft's computer to solve any problems it might encounter. Apollo 8. Apollo 9. Apollo 10. Apollo 11. Without her code, none of those missions could have been completed. For ages 4 to 8.

Space Explorer 6-in-1 Activity Box

$23.99. Available on Amazon

This arts and crafts science box includes six activities — Rocket Science Experiment, Starry Kaleidoscope, Lace the Constellations, Solar System Wind Chime, and the Space Explorer Board Game — and all items for each activity are included along with easy to understand instructions. This kit engages kids to learn through creative play. Children can use their imagination, learn practical skills, and build confidence. The kit is safe, mess-free, and fun for girls and boys. For ages 7 to 10.

Our Planet (Infographics – How It Works)

Gareth Stevens Publishing, 2018, 32 pp., Hardcover. $26.60. www.garethstevens.com

Earth science is made up of so many topics: weather, landforms, and even natural disasters. It can take a lot of time to learn about the details of each. Infographics are the perfect way to cover a lot of these subject areas in less time, including why earthquakes happen, the water cycle, and how mountains form, as well as many other parts of the Earth science curriculum. Each chapter aims to involve readers in what they're learning through succinct text and colorful, creative diagrams. In addition, "Try This" boxes suggest activities and questions through which readers can apply their knowledge. For ages 8 to 11.

Mission to Space

White Dog Press, 2016, 24 pp., Hardcover. $19.99. Available on Amazon

Astronaut John Herrington shares his passion for space travel and his Chickasaw heritage as he gives children a glimpse into his astronaut training at NASA and his mission to the International Space Station. Learn what it takes to train for space flight, see the tasks he completed in space, and join him on his spacewalk 220 miles above Earth. This unique children's book is illustrated with photos from Herrington's training and space travel and includes an English-to-Chickasaw vocabulary list with space-related terms. For ages 5 to 6.

Gears! Gears! Gears!® Space Explorers Building Set

$39.99. www.learningresources.com

Design your own universe with this building set — there are so many possibilities! Place the handle into any gear to make all the pieces move. This set can engage children with various learning styles, including visual and tactile, and can help develop skills such as counting, sorting, matching, patterning, problem-solving, cause-and-effect, critical thinking, sequential thought, spatial relationships, creativity, fine motor skills, eye-hand coordination, visual processing, and color identification. The 77-piece set includes interlocking bases, gears, connectors, handle, astronaut figures, planets, Sun, spaceship, flag, stickers, and an activity guide. Works with all Gears! Gears! Gears!® sets. For ages 4 and up.

Exoplanets Game

$39.95. store.greaterthangames.com

Exoplanets is a dynamic game for two to four players. Each player contributes to the creation of an entire planetary system. Each player's role is to expand the system by adding new planets, create and evolve life forms, and fulfill various tasks. To fulfill these tasks, you will manipulate the planetary system in any way necessary, potentially altering the relations between planets and possibly even the life-giving star at the system's center. For ages 12 and up.

Calendar

2018 Upcoming Events

July

Unveiling the Physics of Protoplanet Formation: Connecting Theory to Observations

- July 15-5
- Aspen, Colorado
- https://www.aspenphys.org/physicists/summer/program/currentworkshops.html

Software Systems in Astronomy (SSFA) — 2018

- July 23-3
- Hilo, Hawaii
- http://astro.uhh.hawaii.edu/Summer/Summer-2018/ssfa18.php

August

Summer School/Workshop on Microsatellites in Planetary and Atmospheric Research

- August 6-11
- Tartu, Estonia
- http://www.nordicastrobiology.net/Tartu2018

Lunar Polar Volatiles

- August 7-9
- Laurel, Maryland
- http://www.hou.usra.edu/meetings/lunarvolatiles2018

9th Planetary Crater Consortium Meeting

- August 8-10
- Boulder, Colorado
- http://www.planetarycraterconsortium.nau.edu/

Physical Chemistry 2018

- August 10
- Amsterdam, The Netherlands
- https://physicalchemistry.euroscicon.com/

The Final Cassini Science Symposium

- August 12-17
- Boulder, Colorado
- http://lasp.colorado.edu/home/2018-cassini-science-symposium/

LSST 2018 Project and Community Workshop

- August 13-17
- Tucson, Arizona
- https://project.lsst.org/meetings/lsst2018/

The 11th Meeting on Cosmic Dust

- August 13-27
- Sagamihara, Japan
- https://www.cps-jp.org/~dust/Welcome.html

Experimental Analysis of the Outer Solar System Workshop

- August 15-17
- Fayetteville, Arkansas
- https://www.hou.usra.edu/meetings/exoss2018/

3rd Planetary CubeSat Science Symposium

- August 16-17
- Greenbelt, Maryland
- https://cubesats.gsfc.nasa.gov/symposium.html

XXXth General Assembly of the International Astronomical Union

- August 20-31
- Vienna, Austria
- http://astronomy2018.univie.ac.at/

Molecular Geobiology EMBO Practical Course

- August 26-31
- Heidelberg, Germany
- https://www.embl.de/training/events/2018/GEO18-01

Comparative Climatology of Terrestrial Planets III

- August 27-30
- Houston, Texas
- https://www.hou.usra.edu/meetings/climatology2018/

A Century of Asteroid Families

- August 28-30
- Vienna, Austria
- http://asteroidfamilies.net/IAU2018/

September

Asteroids and Comets — Inside Out Workshop

- September 4-6
- Tampere, Finland
- http://www.tut.fi/acio18

Physics of Coments After the Rosetta Mission: Unresolved Problems

- September 5-7
- Stara Lesna, Slovakia
- https://www.astro.sk/AFTERROSETTA/

Triple Evolution and Dynamics Trendy-2

- September 10-14
- Leiden, The Netherlands
- http://www.lorentzcenter.nl/lc/web/2018/1016/info.php3?wsid=1016&venue=Oort

ASP2018: Advancing Astronomy for All

- September 10-13
- Rohnert Park, California
- ttps://www.astrosociety.org/about-us/asp-annual-meetings

Observing the Sun as a Star: Would We Find the Solar System if We Saw It?

- September 10-13
- Gottingen, Germany
- http://sun-as-a-star.astro.physik.uni-goettingen.de/

International Venus Conference 2018

- September 11-14
- Niseko, Japan
- https://www.cps-jp.org/~akatsuki/venus2018/

Outer Planets Analysis Group

- September 11-12
- Pasadena, California
- https://www.lpi.usra.edu/opag/

SSB Committee on Astrobiology and Planetary Science

- September 12-13
- Irvine, California
- http://sites.nationalacademies.org/SSB/SSB_067577#Meetings_and_Eventshttp://sites.nationalacademies.org/SSB/SSB_067577#Meetings_and_Events

International Workshop on Instrumentation for Planetary Missions (IPM-2018)

- September 12-14
- Berlin, Germany
- https://ipm2018.org/

European Planetary Science Congress 2018 (EPSC)

- September 16-21
- Berlin, Germany
- https://www.epsc2018.eu/

The 3rd Tautenburg School for Advanced Astronomical Observations: Echelle Spectroscopy

- September 20-1
- Tautenburg, Germany
- http://www.tls-tautenburg.de/TLS/fileadmin/homepage/Fall_school_2018/index.html

Extrasolar Cloud Academy: Cloud Formation and Properties in Extrasolar Planets

- September 23-28
- Grenoble, France
- http://eos-nexus.org/clouds/

SPIE Asia-Pacific Remote Sensing

- September 24-27
- Honolulu, Hawaii
- http://spie.org/AE/conferencedetails/multispectral-hyperspectral-and-ultraspectral-remote-sensing?SSO=1

European Astrobiology Conference (EANA 2018)

- September 24-28
- Berlin, Germany
- http://www.eana-net.eu/index.php?page=Conferences/EANA2018

NASA Technosignatures Workshop

- September 26-28
- Houston, Texas
- https://www.hou.usra.edu/meetings/technosignatures2018/

Bombardment: Shaping Planetary Surfaces and Their Environments

- September 30-3
- Flagstaff, Arizona
- https://www.hou.usra.edu/meetings/bombardment2018/

October

Late Mars Workshop

- October 1-3
- Houston, Texas
- https://www.hou.usra.edu/meetings/latemars2018/

HoRSE: High Resolution Spectroscopy for Exoplanet Atmospheres

- October 1-5
- Nice, France
- https://horse.sciencesconf.org

The Ninth Moscow Solar System Symposium (9M-S3)

- October 8-12
- Moscow, Russia
- https://ms2018.cosmos.ru/

Europa Deep Dive 2: Composition

- October 9-11
- Houston, Texas
- https://www.hou.usra.edu/meetings/europadeepdive2018/

7th Joint Workshop on High Pressure, Planetary and Plasma Physics (HP4)

- October 10-12
- Berlin, Germany
- https://indico.desy.de/indico/event/18893/

Multi-Dimensional Characterization of Distant Worlds

- October 15-19
- Ann Arbor, Michigan
- https://sites.lsa.umich.edu/mira3d

50th Meeting of the AAS Division for Planetary Sciences

- October 21-26
- Knoxville, Tennessee
- https://aas.org/meetings/dps50

Chromatography 2018

- October 25-26
- Rome, Italy
- https://www.meetingsint.com/conferences/chromatography

Towards an All-Sky Radio SETI Telescope

- October 30-31
- Manchester, United Kingdom
- http://www.jodrellbank.manchester.ac.uk/news-and-events/wide-field-seti-workshop/

Cosmic Dust and Magnetism

- October 31-2
- Daejeon, South Korea
- http://coma.kasi.re.kr/cosdm2018/home.html

November

2018 Geological Society of America Annual Meeting

- November 4-7
- Indianapolis, Indiana
- https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2018.aspx

16th Venus Exploration Analysis Group Meeting

- November 6-8
- Laurel, Maryland
- https://www.lpi.usra.edu/vexag/

2nd GeoPlaNet Thematic School — Fluid-Rock Interactions in the Solar System

- November 12-16
- Nantes, France
- https://lpg-umr6112.fr/TS-GeoPlaNet

5th International Conference on Artificial Light at Night 2018

- November 12-14
- Salt Lake City, Utah
- https://artificiallightatnight.weebly.com/

Annual Meeting of the Lunar Exploration Analysis Group

- November 13-16
- Columbia, Maryland
- https://www.hou.usra.edu/meetings/leag2018/

December

Hayabusa 2018: 6th Symposium of the Solar System Materials

- December 4-7
- Tokyo, Japan
- http://curation.isas.jaxa.jp/symposium/2018/index.html

Ninth Symposium on Polar Science

- December 4-7
- Tokyo, Japan
- http://www.nipr.ac.jp/symposium2018/

2018 AGU Fall Meeting

- December 10-14
- Washington, DC
- http://fallmeeting.agu.org