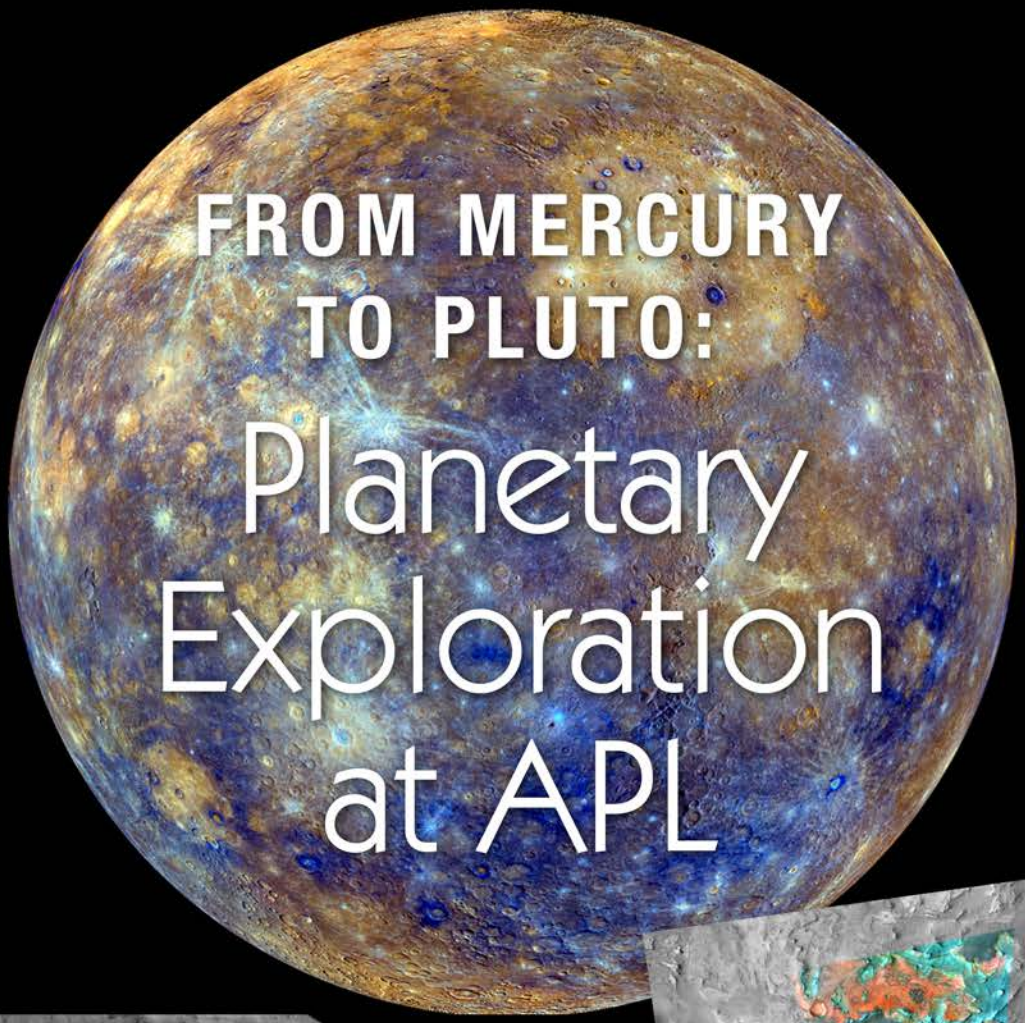
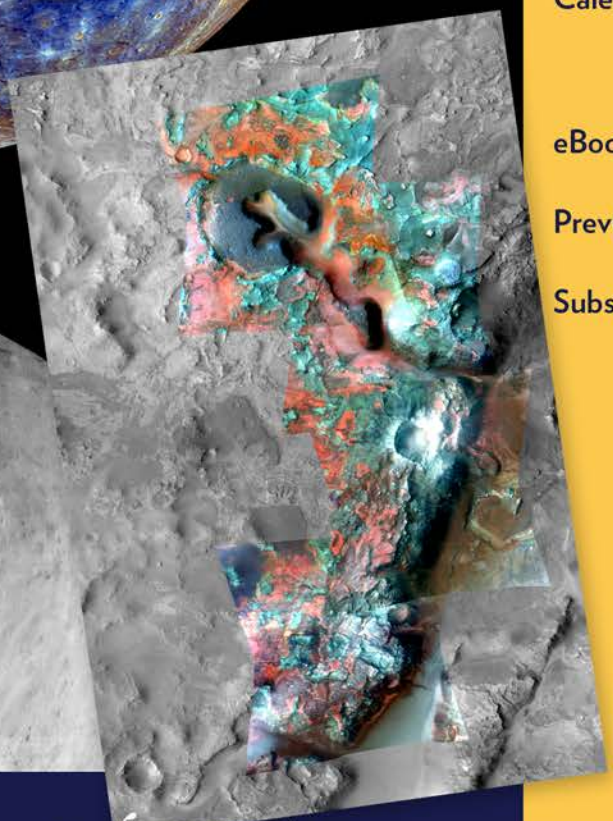


FROM MERCURY TO PLUTO: Planetary Exploration at APL



CONTENTS

Lunar and Planetary Information

BULLETIN

Universities Space Research Association — Lunar and Planetary Institute

June 2015
Issue 141

www.lpi.usra.edu/lpib

— Ben Bussey* and Scott Murchie, Johns Hopkins University Applied Physics Laboratory
(*now at NASA Headquarters)

Note from the Editors: This issue's lead article is the fifth in a series of reports describing the history and current activities of the planetary research facilities funded by NASA and located nationwide. This issue features the Planetary Exploration Group at the John Hopkins University's Applied Physics Laboratory, which has emerged over the last decade as one of the leading planetary science research centers in the U.S.

— Paul Schenk and Renee Dotson

In the last 10 years, the Planetary Exploration Group at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland, has emerged as a leading planetary science research center. Its almost 40 scientists study all aspects of solar system bodies, and work on a mixture of mutually complementary mission and research activities. The group resides within the more than 700-strong Space Exploration Sector at APL. The Sector has the capability to implement a mission from initial conception through design, fabrication, launch, operations, and data analysis.

Space at APL: How the Planetary Exploration Group at APL came to be traces back to the beginning of the U.S. space program. In 1939, a young James Van Allen became a Research Fellow at the Carnegie Institute of Washington's Department of Terrestrial Magnetism, in Merle Tuve's nuclear physics laboratory. Tuve led an effort to develop the proximity fuse, to increase effectiveness of naval anti-aircraft fire. In April 1942, the Johns Hopkins University established APL to host work on the proximity fuse, with Tuve as its Director and Van Allen on staff. After the war, APL worked with captured German V-2 rockets and used one to acquire the first space image showing Earth's curvature. In 1951, Van Allen moved to the University of Iowa, but APL continued to pursue the field of space.

In 1958, inspired by the Doppler shift in the radio signal from the newly launched Soviet Sputnik satellite as it passed overhead, APL scientists discovered how to determine — from the changing frequencies of orbiting satellite signals — one's position on the ground. Thus was born satellite navigation, and the Transit program. That same year, Van Allen's radiation sensor on NASA's Explorer 1 spacecraft detected Earth's radiation belts, which were later named for him. Space research at APL began in 1960 with the quest to understand the effects of that radiation on space systems. APL space physicists began to measure and conduct basic research on the magnetic fields and radiation in the near-Earth space environment. As space science grew at APL over the next 55 years, the lab designed, developed, and launched 68 spacecraft and more than 150 instruments.

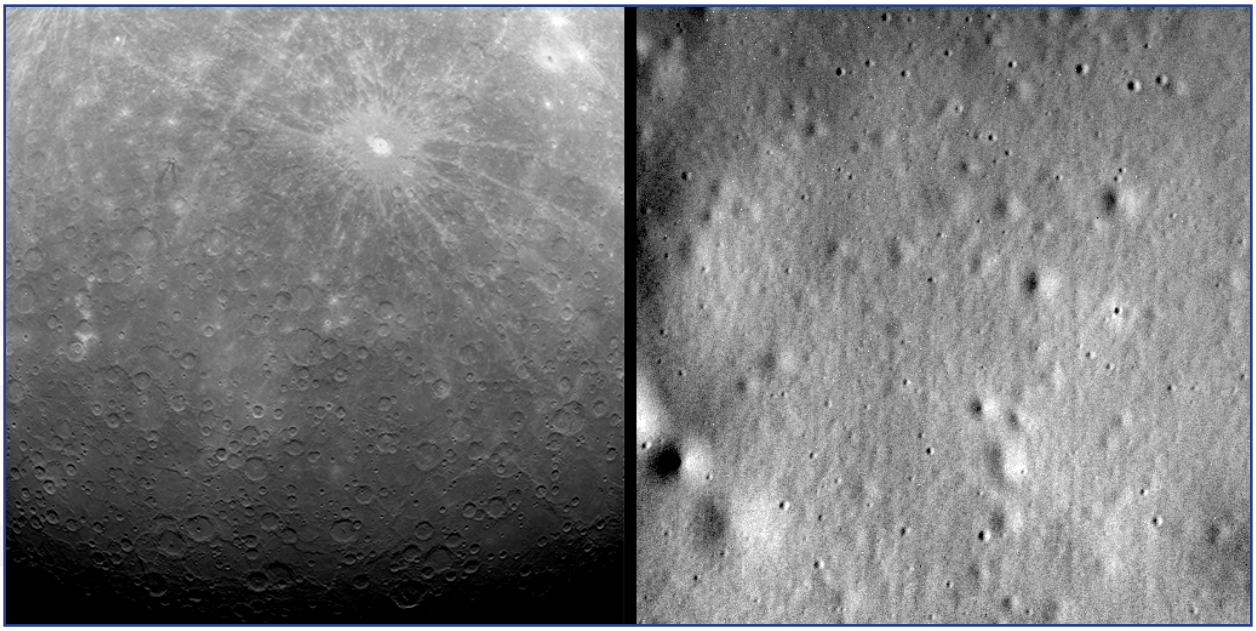
APL's involvement with solar system exploration began in 1965 when a young APL space physicist, Stamatios "Tom" Krimigis, was part of Van Allen's science team for the radiation detector on the Mariner 4 Mars flyby mission. From that time period through the 1990s, APL's "Space Department" (now the Space Exploration Sector) was involved in planetary exploration by building space-physics-oriented instruments and analyzing their measurements of charged particles and magnetic fields.

Planetary Geology and Astronomy: Flash forward to 1992. NASA's robotic missions to other planets had become so large and expensive that one could be launched only every 5–10 years. The loss of even one — like Mars Observer in 1993 — would be a major setback. To make planetary exploration more nimble, affordable, and able to absorb the loss of a mission, NASA conceived the Discovery Program. Its missions would be selected competitively, with stringent cost caps and short development times compared to previous "flagship" missions. Two were selected initially: Mars Pathfinder, a return to Mars' surface after 20 years since Viking, was awarded to the Jet Propulsion Laboratory (JPL). In a break with the tradition of JPL leading all interplanetary missions, the second Discovery selection, the Near-Earth Asteroid Rendezvous (NEAR) mission, was awarded to APL.

Driven by NEAR and the Discovery Program, APL entered the field of planetary geology and astronomy. Five of NEAR's six instruments — a camera, infrared spectrometer, X-ray spectrometer, gamma-ray spectrometer, and laser rangefinder — were focused on the geology of NEAR's target, asteroid 433 Eros. Only NEAR's magnetometer was aligned with APL's existing space physics expertise. To provide science oversight of development, calibration, and day-to-day function of those instruments, APL needed expertise in geology and geophysics. Over a period of five years, a core group of a half-dozen planetary geologists was brought onboard, as part of APL's space physics group. In the same timeframe, work on the Space Department's national security missions was winding down. New civilian space work was pursued full throttle. In 1997 and 1999, APL won two more Discovery missions, the COmet Nucleus TOUR (CONTOUR), and the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER). In 2001, two more opportunities arose. NASA announced the New Frontiers line of missions, a more ambitious version of Discovery, with its first target being Pluto. In addition, payload proposals were sought for the Mars Reconnaissance Orbiter (MRO). In response, APL submitted proposals for New Horizons, a Pluto flyby mission, and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). Both were selected.

APL had become a rising star in planetary exploration, as well as a destination for professionals interested in basic as well as applied research. From 2002 to 2014 the number of planetary scientists grew from 6 to almost 40, studying the solar system from Mercury to Pluto and beyond. In 2003 they formed a new group distinct from the space physics group, the "Planetary Exploration Group" (hereafter referred to as the planetary group).

Mercury: APL conceived, built, launched, and operated the MESSENGER mission, which reached orbit around Mercury in March 2011. The planetary group contributed not only to scientific analysis of the data, but also to mission activities that included planning observations, calibrating datasets, and delivering products to the Planetary Data System (PDS). Many of MESSENGER's instruments are a focus for the research projects in the planetary group. Data from the Gamma-Ray and Neutron Spectrometer (GRNS) instrument have determined the chemical composition of Mercury's surface and the hydrogen content of Mercury's north polar region. Measurements from the Mercury Laser Altimeter (MLA) have been used to investigate the morphology of craters and surface roughness. The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) has provided insight into the spectral properties of Mercury's surface. Radio science investigations have yielded knowledge of Mercury's shape. Images from the Mercury Dual Imaging System (MDIS) have been used to explore Mercury's geologic features, from global stratigraphy and surface composition to small-scale hollows. The planetary group collaborates with its sister space physics groups at APL, where Mercury's exosphere and magnetosphere are studied. After two extended missions, MESSENGER came to a spectacular end on April 30, 2015, when having exhausted its

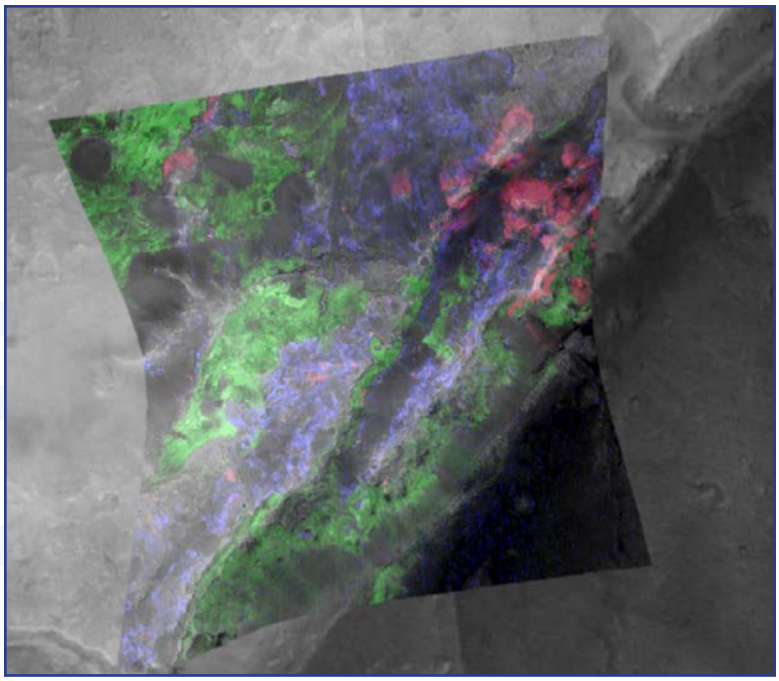


Left: The first image acquired by MESSENGER from Mercury orbit was a 2.7-kilometer/pixel (1.67-mile/pixel) view from high over the southern hemisphere. The large bright-rayed crater is Debussy. Right: The last image taken before Mercury impact shows a region 1 kilometer (0.62 miles) across and features as small as 2 meters (6.56 feet) across. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

fuel, it impacted the mercurian surface at 13,277 kilometers per hour (8750 miles per hour)! *(Editor's note: For more information about the conclusion of the MESSENGER mission, see the related article in the News from Space section of this issue.)*

Moon: APL's planetary group has a number of scientists focused on lunar science and exploration. Lunar work at APL expanded with NASA's selection in 2004 of two synthetic aperture radars (SARs) to fly in lunar orbit. One, called Forerunner, flew on the Indian Space Research Organization (ISRO) Chandrayaan-1 spacecraft, and Mini-RF is on NASA's Lunar Reconnaissance Orbiter (LRO). The two instruments collected more than 1000 strips of data in S- and X-bands, mapping approximately two-thirds of the lunar surface (including >95% of both polar regions) at a resolution of 30 meters (98 feet). Significant achievements include the first radar mapping of the lunar farside and the floors of permanently shadowed craters that cannot be seen from Earth. LRO's Mini-RF collected the first-ever bistatic radar images with non-zero bistatic angles, using the Arecibo radio telescope as the transmitter. The planetary group's scientists are also involved with other LRO instruments, including the LRO Camera (LROC), Lyman Alpha Mapping Project (LAMP), Lunar Orbiter Laser Altimeter (LOLA), and Diviner infrared radiometer, and their research has covered a wide variety of topics including ice in permanently shadowed craters, the nature of impact melt, crustal composition, and the Moon's spectral properties.

The planetary group is also active in a wide variety of lunar research outside of active missions. An APL-led team was selected as one of the first NASA Lunar Science Institute (NLSI) teams, whose focus was the lunar poles. Its research consisted of a mixture of science and engineering, all with the goal of turning "*Luna incognita"* into "*Luna cognita.*" Following NLSI, APL successfully proposed to the Solar System Exploration Research Virtual Institute (SSERVI) program. The VOlatiles Regolith Thermal Investigations Consortium for Exploration and Science (VORTICES) team is studying a set of interconnected questions that encompass regolith-volatile systems of the Moon and small planetary objects in the context of science and exploration.

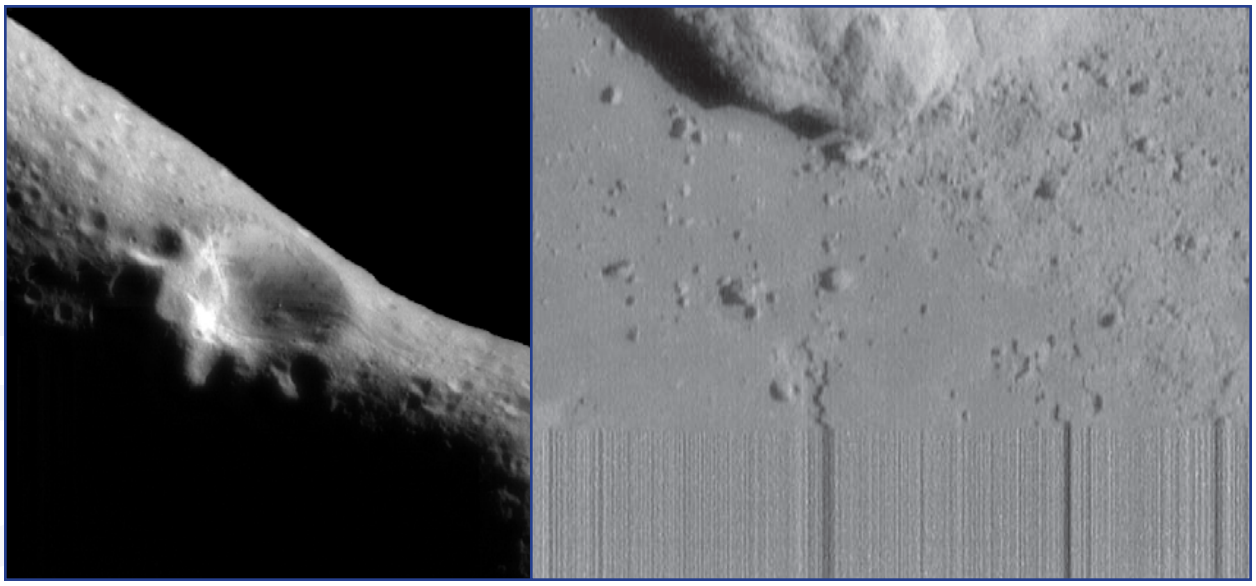


CRISM image FRT00009971 shows early Noachian rocks in the Nili Fossae region. Colors indicate the presence of different minerals. Red indicates low-calcium pyroxene-rich igneous rocks, which are largely restricted to Noachian units. Green indicates alteration to Fe/Mg-bearing phyllosilicate, or clay minerals, and blue indicates even greater degrees of alteration to Al-rich phyllosilicates. The image is 10 kilometers (6.2 miles) across and overlain on MRO Context Imager (CTX) data. Credit: NASA/Jet Propulsion Laboratory/Johns Hopkins University Applied Physics Laboratory.

Mars: The planetary group operates the APL-built CRISM imaging spectrometer on MRO. CRISM has operated in Mars orbit for 9 years, mapped over 95% of the planet at 200 meters/pixel (656 feet) scale, and collected over 30,000 high-resolution images at 20 or 40 meters/pixel (65.6 or 131 feet) scale. These data are a primary input for the selection of sites for landed and rover missions and for rover traverse planning. They have led to key discoveries about crustal evolution and volatiles on Mars: observations of intact carbonate bedrock, occurrences of more than 30 different minerals, a dozen types of ancient wet environments including several that could have been habitable, and widespread low-grade metamorphic alteration of the Noachian crust.

APL's planetary geoscientists serve as Co-Investigators and Participating Scientists on the Mars Science Laboratory (MSL) Curiosity rover and Mars Exploration Rover (MER) Opportunity Pancam, Mastcam, and ChemCam investigations. Their research includes mineralogy and photometric properties of rocks and soils at the landing sites, eolian processes at Gale Crater including ripple landforms and dune fields, and the nature of the terrain on which the rovers drive. Planetary group scientists are also involved in the Mars-2020 rover mission as Co-Is on Mastcam-Z, SuperCam, and the MEDA meteorological package.

Asteroids: Asteroid research has been an identifying hallmark of the planetary group since the NEAR mission. Key findings at 433 Eros include "space weathering" distinct from that which occurs on the Moon, homogeneous surface mineralogic composition consistent with ordinary chondrite, elemental composition consistent with ordinary chondrite, depletion in sulfur in the upper millimeters probably by space weathering, processes by which grooves form, and regolith migration to form plains or "ponds." APL planetary scientists participated in the Hayabusa mission to the small rubble-pile asteroid 25143 Itokawa, focusing on the shape and topography of the asteroid from imaging and laser altimetry, and on how impacts modify the asteroid surface. On the Dawn mission to 4 Vesta and 1 Ceres, members of the planetary group have been involved in every investigation. Their findings at Vesta include the organization of grooves into two large systems, how groove patterns constrain internal morphology, space weathering distinct from that on the Moon and Eros, exogenic carbonaceous materials, and how those materials may contribute to formation of "pitted terrain." The Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer (OSIRIS-REx) mission, a mission to collect and return



Left: NEAR's first image of Eros taken from orbit around the asteroid shows the 9-kilometer (5.6-mile) crater Psyche. Right: NEAR's last image prior to landing covers a region 6 meters (19.7 feet) across and shows the edge of the small "pond" of dust where the spacecraft came to rest. The lower part of the image is blurred due to the loss of data as the spacecraft touched down. Credit: NASA/Johns Hopkins University Applied Physics Laboratory.

samples from the small, carbon-rich asteroid 101955 Bennu, is set to launch in 2016, and scientists from the planetary group are playing leading roles in the laser altimetry investigation and determination of asteroid shape.

Jovian and Saturnian Systems: APL planetary scientists are involved in the Cassini mission to Saturn, investigating the surface morphology of Saturn's satellites with a focus on eolian processes on Titan, the only solar system body besides Earth with a dense nitrogen-dominated atmosphere. Together with JPL, APL has been studying how to explore Jupiter's moon Europa. NASA recently announced the selection of instruments for the Europa Multiple Flyby Mission, and APL planetary scientists are involved in four of the nine instruments, including the APL-led Europa Imaging System (EIS) and Plasma Instrument for Magnetic Sounding (PIMS). The Mapping Imaging Spectrometer for Europa (MISE) is a collaboration between JPL and APL. APL planetary scientists are also playing key roles in the project science office, and participate in the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON). APL scientists conduct research on the magnetospheres of Jupiter and Saturn from *in situ* data, including the structure of the planetary radiation belts, major dynamic processes, and weathering of the satellites by charged particles, and they participate in the particle experiments on Cassini, Juno, and the Jupiter Icy Moon Explorer (JUICE).

Pluto: APL's planetary group members play a major role on New Horizons, including serving as project scientist, and supporting the APL-built LOng Range Reconnaissance Imager (LORRI), which will provide 100 meter/pixel (328 feet) images of selected regions of Pluto during the flyby on July 14, 2015 — 50 years to the day from the Mariner 4 flyby of Mars and the beginning of planetary science at APL. LORRI demonstrated its superior resolution during the 2007 Jupiter flyby when it imaged Io's volcanos, Jupiter's atmosphere, polar lightning on Jupiter's nightside, and the jovian ring system. APL will be ground zero during the Pluto encounter when hundreds of scientists, media, and the public will

gather to see the initial results. Planetary group scientists are part of the geological investigations of Pluto and its six satellites; the compositions of their surfaces; and the composition, structure, and loss of Pluto's atmosphere.

Comets: Together with NASA's Glenn Research Center and SwRI, APL developed a balloon for conducting high-value planetary science measurements. The Balloon Observation Platform for Planetary Science (BOPPS) mission launched from Ft. Sumner, New Mexico, on September 25, 2014, ascending to 3658 meters (120,000 feet) (above 99.5% of the atmosphere). The high altitude allows BOPPS instruments to measure small amounts of water or hydroxyl, carbon dioxide, and trace organic materials on solar system bodies. BOPPS has measured Comet Siding Spring and Comet C/2014 E2 Jacques, and characterized hydrated minerals on asteroid 1 Ceres.

APL planetary scientists also participate in ESA's Rosetta mission, the first mission to rendezvous with a comet nucleus and land on its surface, by studying coma composition and nucleus surface reflectance as revealed by ultraviolet spectroscopy. They are involved in numerous telescopic observations not only of comets, but also of accretion disks surrounding other stars.

Laboratory Investigations: Finally, the planetary group maintains first-rate laboratory space, including a meteorite lab equipped for microscopic compositional analyses and petrologic experiments, and a spectroscopy lab with an environmental chamber that covers ultraviolet to infrared wavelengths. The group also maintains an impact lab enabling impacts and ejecta emplacement to be studied using a vertical gun and catapult, as well as a planetary nuclear spectroscopy laboratory.

APL's unique development of its planetary group provides a strong foundation that links its science research to a half-century of developing space science experimental capabilities. The close proximity of the group's almost 40 planetary scientists to space physicists and to engineers, designers, and operations specialists enables planetary science investigations to be implemented over their full life-cycle — from identifying key science questions; conceptualizing an experiment; designing, building, and launching it; and finally to analyzing the returned data — and identifying the next key questions.

About the Cover:

Top: This colorful view of Mercury was produced by using images taken by the Wide Angle Camera (WAC) of the Mercury Dual Imaging System (MDIS) during MESSENGER's primary mission. These colors are not what Mercury would look like to the human eye, but rather the colors enhance the mineralogical and physical differences between the rocks that make up Mercury's surface. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

Lower left: NEAR Shoemaker image mosaic of asteroid 433 Eros. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Arizona State University.

Lower right: CRISM false-color infrared mosaic of the Nili Fossae region of Mars. Gray, red, blue-gray, and green colors correspond to rock units dominated by basalt, olivine, phyllosilicates, and carbonates. Credit: NASA/Jet Propulsion Laboratory/Johns Hopkins University Applied Physics Laboratory/Arizona State University.

About the Authors:

Ben Bussey is a planetary scientist who is currently the Chief Exploration Scientist in NASA's Human Exploration and Operations Mission Directorate. He earned a B.A. in Physics from Oxford University and a Ph.D. in Planetary Geology at University College London before moving to the U.S. He gained both science and mission experience while working at the Lunar and Planetary Institute in Houston, the European Space Agency, Northwestern University, and the University of Hawaii, before joining the Johns Hopkins University Applied Physics Laboratory, where he was the Group Supervisor for the Planetary Exploration Group until his appointment at NASA. Bussey's research concentrates on the remote sensing of the surfaces of planets, particularly the Moon. He has a particular interest in the lunar poles, producing the first quantitative illumination maps of the polar regions.

Scott Murchie is the Group Supervisor for the Planetary Exploration Group in the Space Exploration Sector of The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. His research focuses on using imaging and spectroscopy to investigate the structure and composition of planetary crusts and their alteration by volatiles, and the composition and evolution of asteroids and small moons. He is a Co-Investigator on the MESSENGER mission and the Mapping Imaging Spectrometer for Europa (MISE) and Principal Investigator on the Compact Imaging Spectrometer for Mars (CRISM). He received his Ph.D. in geology from Brown University.

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*)

Renée Dotson,
Production Editor (*rdotson@hou.usra.edu*)

Copy deadline for the next issue: August 15, 2015

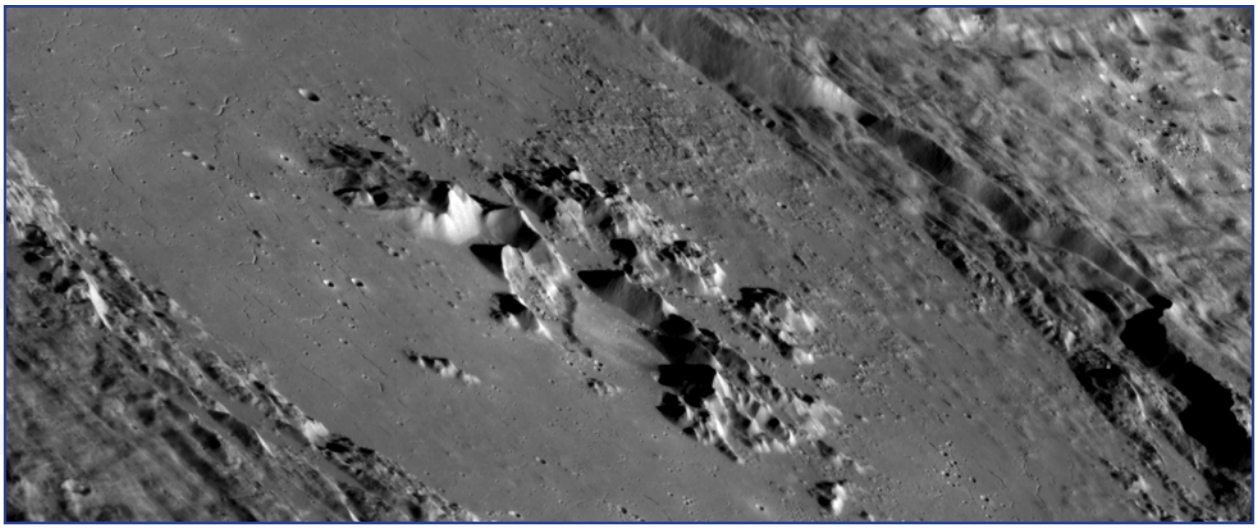
To be added to the list to receive notification by e-mail of future issues, please send your e-mail address to *lpibed@lpi.usra.edu*, or visit *www.lpi.usra.edu/publications/newsletters/lpib/subscribe/index.cfm*.

The *Bulletin* is published quarterly by the Lunar and Planetary Institute (LPI), 3600 Bay Area Boulevard, Houston TX 77058. Material in this issue may be copied without restraint for library, abstract service, education, or personal research purposes.

ISSN 1534-6587

The LPI is operated by the Universities Space Research Association under Award No. NNX15AL12A from the Science Mission Directorate of the National Aeronautics and Space Administration. Any opinions, findings, and conclusions or recommendations expressed in this issue are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

NASA Completes MESSENGER Mission with Expected Impact on Mercury's Surface



This oblique view of 116-kilometer-diameter (72-mile-diameter) Abedin crater is one of the final images released by the MESSENGER mission on April 16. The mosaic of oblique images highlights the spectacular interior of Abedin crater. The crater floor is covered with once-molten rock melted by the impact event that formed Abedin. Cracks that formed as this melt cooled are visible. Particularly intriguing is the shallow depression that lies amid the central peaks of the crater and may be volcanic in origin. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/ Carnegie Institution of Washington.

A NASA planetary exploration mission came to a planned, but nonetheless dramatic, end on April 30 when it slammed into Mercury's surface at about 14,082 kilometers per hour (8750 miles per hour) and created a new crater on the planet's surface. Mission controllers at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland, confirmed NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft impacted the surface of Mercury, as anticipated, at 3:26 p.m. EDT. Mission control confirmed end of operations just a few minutes later, at 3:40 p.m., when no signal was detected by NASA's Deep Space Network (DSN) station in Goldstone, California, at the time the spacecraft would have emerged from behind the planet. This conclusion was independently confirmed by the DSN's Radio Science team, which also was monitoring for a signal from MESSENGER.

"Going out with a bang as it impacts the surface of Mercury, we are celebrating MESSENGER as more than a successful mission," said John Grunsfeld, associate administrator for NASA's Science Mission Directorate in Washington. "The MESSENGER mission will continue to provide scientists with a bonanza of new results as we begin the next phase of this mission — analyzing the exciting data already in the archives, and unravelling the mysteries of Mercury."

Prior to impact, MESSENGER's mission design team predicted the spacecraft would pass a few miles over a lava-filled basin on the planet before striking the surface and creating a crater estimated to be as wide as 15 meters (50 feet). MESSENGER's lonely demise on the small, scorched planet closest to the Sun went unobserved because the probe hit the side of the planet facing away from Earth, so groundbased telescopes were not able to capture the moment of impact. Spacebased telescopes were also unable to view the impact, as Mercury's proximity to the Sun would damage optics.

MESSENGER's last day of real-time flight operations began at 11:15 a.m., with initiation of the final delivery of data and images from Mercury via a 70-meter (230-foot) DSN antenna located in Madrid, Spain. After a planned transition to a 34-meter (111-foot) DSN antenna in California, at 2:40 p.m., mission operators later confirmed the switch to a beacon-only communication signal at 3:04 p.m. The mood in the Mission Operations Center at APL was both somber and celebratory as team members watched MESSENGER's telemetry drop out for the last time, after more than four years and 4105 orbits around Mercury. "We monitored MESSENGER's beacon signal for about 20 additional minutes," said mission operations manager Andy Calloway of APL. "It was strange to think during that time MESSENGER had already impacted, but we could not confirm it immediately due to the vast distance across space between Mercury and Earth."

MESSENGER was launched on August 3, 2004, and began orbiting Mercury on March 17, 2011. Although it completed its primary science objectives by March 2012, the spacecraft's mission was extended two times, allowing it to capture images and information about the planet in unprecedented detail. During a final extension of the mission in March, referred to as XM2, the team began a hover campaign that allowed the spacecraft to operate within a narrow band of altitudes from 5 to 35 kilometers (3 to 22 miles) from the planet's surface. On April 28, the team successfully executed the last of seven daring orbit correction maneuvers that kept MESSENGER aloft long enough for the spacecraft's instruments to collect critical information on Mercury's crustal magnetic anomalies and ice-filled polar craters, among other features. After running out of fuel, and with no way to increase its altitude, MESSENGER was finally unable to resist Mercury's gravitational pull.

"Today we bid a fond farewell to one of the most resilient and accomplished spacecraft to ever explore our neighboring planets," said Sean Solomon, MESSENGER's principal investigator and director of Columbia University's Lamont-Doherty Earth Observatory in Palisades, New York. To learn more about the accomplishments of NASA's MESSENGER mission, visit *https://www.youtube.com/watch?v=ENwD31EDFjc* and *http://www.nasa.gov/messenger*.

Single Site on Mars Advanced for 2016 NASA Lander

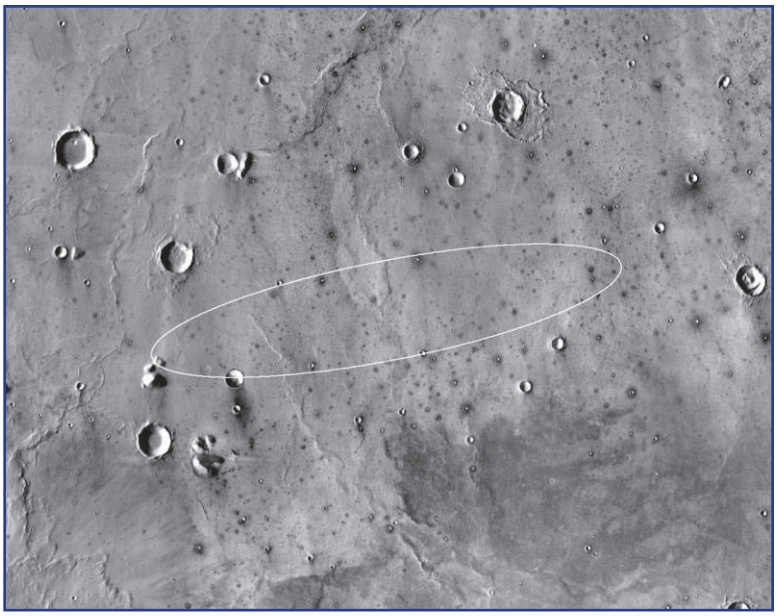
NASA's next mission to Mars, scheduled to launch one year from today to examine the Red Planet's deep interior and investigate how rocky planets like Earth evolved, now has one specific site under evaluation as the best place to land and deploy its science instruments.

The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission is scheduled to launch from Vandenberg Air Force Base, California. The launch period runs from March 4 to March 30, 2016, and will mark the first California launch of an interplanetary mission. Installation of science-instrument hardware onto the spacecraft has begun, and a key review has given thumbs-up to integration and testing of the mission's component systems from several nations participating in the international project.

The landing-site selection process evaluated four candidate locations selected in 2014. The quartet is within the flat-lying "Elysium Planitia," less than 5° north of the equator, and all four appear safe for InSight's landing. The single site will continue to be analyzed in coming months for final selection later this year. If unexpected problems with this site are found, one of the others would be imaged and could be selected. The favored site is centered at about 4°N latitude and 136°E longitude.

"This is wondrous terrain, exactly what we want to land on because it is smooth, flat, with very few rocks in the highest-resolution images," said InSight's site-selection leader, Matt Golombek of NASA's Jet Propulsion Laboratory (JPL).

Mars orbiters have provided detailed information about the candidate sites, which are mapped as landing ellipses about 130 kilometers (81 miles) west-to-east by about 27 kilometers (17 miles) north-to-south. An ellipse covers the area within which InSight has odds of about 99% of landing, if targeted for the ellipse center. Several types of terrain, such as "cratered," "etched," and "smooth" were mapped in each ellipse. The one chosen for final evaluations has the highest proportion in the smooth category.



This map shows the single area under continuing evaluation as the InSight mission's Mars landing site, as of a year before the mission's May 2016 launch. The finalist ellipse marked is within the northern portion of flat-lying Elysium Planitia about 4° north of Mars' equator. Credit: NASA/JPL-Caltech.

After InSight reaches Mars on September 28, 2016, the mission will assess properties of the planet's crust, mantle, and core. The interior of Mars has not been churned as much as Earth's because Mars lacks the tectonic activity that recycles Earth's crustal plates back into the mantle. Thus, Mars offers an opportunity to find clues no longer present on Earth about how rocky planets such as Earth, Mars, Venus, and Mercury formed and evolved.

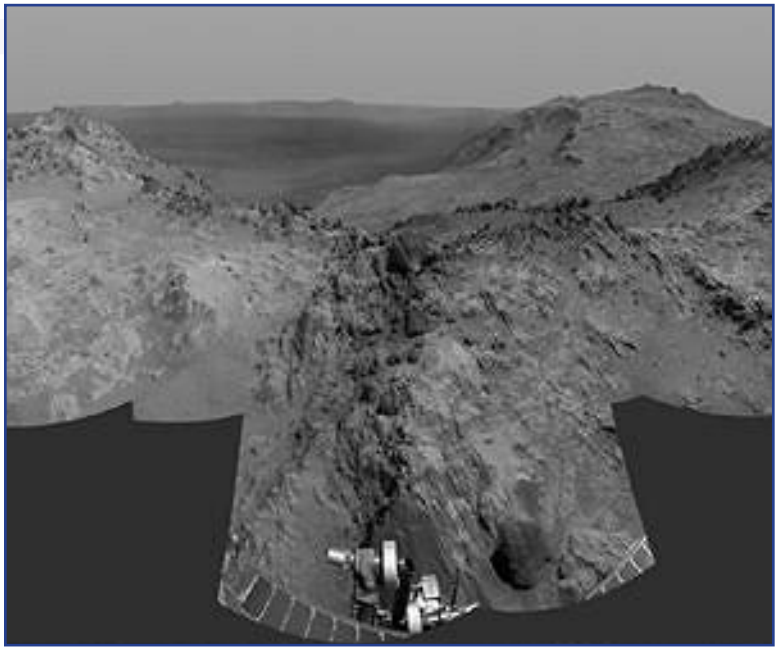
InSight's primary science will study the planet's interior, not surface features. Besides safety for the landing, the main site-selection criterion is for the ground within reach of the lander's robotic arm to be penetrable for a heat-flow probe designed to hammer itself into the soil to a depth 3–5 meters (yards).

Evidence that the ground will be suitable for the probe, rather than rock solid, comes from assessment by the Thermal Imaging System on NASA's Mars Odyssey orbiter of how quickly the ground cools at night or warms in sunlight, and evaluation of images from the High Resolution Imaging Science Experiment on NASA's Mars Reconnaissance Orbiter.

For more information, visit *http://insight.jpl.nasa.gov/home.cfm*.

Opportunity Mars Rover Passes Marathon Distance

There was no tape draped across a finish line, but NASA is celebrating a win. The agency's Mars Exploration Rover Opportunity completed its first Red Planet marathon on March 24 — 42.195 kilometers (26.219 miles) — with a finish time of roughly 11 years and 2 months. "This is the first time any human enterprise has exceeded the distance of a marathon on the surface of another world," said John Callas, Opportunity project manager at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. "A first time happens only once." To celebrate, the rover team at JPL planned a marathon-length relay run at the laboratory to be held the following week.



Cumulative driving by NASA's Mars Exploration Rover Opportunity surpassed marathon distance on March 24, 2015, as the rover neared a destination called "Marathon Valley," which is middle ground of this dramatic view from early March. Credit: NASA/JPL-Caltech.

The long-lived rover surpassed the marathon mark during a drive of 46.5 meters (153 feet). Last year, Opportunity became the long-distance champion of all off-Earth vehicles when it topped the previous record set by the former Soviet Union's Lunokhod 2 Moon rover. "This mission isn't about setting distance records, of course; it's about making scientific discoveries on Mars and inspiring future explorers to achieve even more," said Steve Squyres, Opportunity principal investigator at Cornell University in Ithaca, New York. "Still, running a marathon on Mars feels pretty cool."

Opportunity's original three-month prime mission in 2004 yielded evidence of environments with liquid water soaking the ground and flowing on the planet's surface. As the rover continued to operate far beyond expectations for its lifespan, scientists chose the rim of Endeavour Crater as a long-term destination. Since 2011, examinations of Endeavour's rim have provided information about ancient wet conditions less acidic, and more favorable for microbial life, than the environment that left clues found earlier in the mission. For more information, visit *http://www.nasa.gov/mission_pages/mer/index.html* and *http://mars.nasa.gov/mer/home/*.

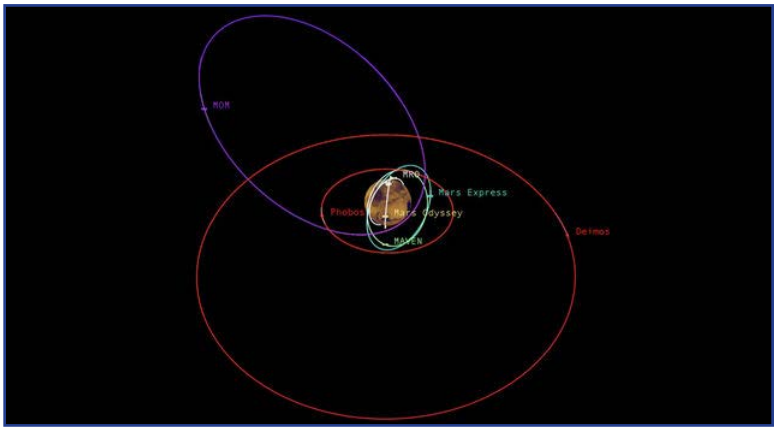
Traffic Control at Mars Gets Busy

NASA has beefed up a process of traffic monitoring, communication, and maneuver planning to ensure that Mars orbiters do not approach each other too closely. Last year's addition of two new spacecraft orbiting Mars brought the census of active Mars orbiters to five, the most ever. NASA's Mars Atmosphere and Volatile Evolution (MAVEN) and India's Mars Orbiter Mission joined the 2003 Mars Express from ESA (the European Space Agency) and two from NASA: the 2001 Mars Odyssey and the 2006

Mars Reconnaissance Orbiter (MRO). The newly enhanced collision-avoidance process also tracks the approximate location of NASA's Mars Global Surveyor, a 1997 orbiter that is no longer working.

It's not just the total number that matters, but also the types of orbits missions use for achieving their science goals. MAVEN, which reached Mars on September 21, 2014, studies the upper atmosphere. It flies an elongated orbit, sometimes farther from Mars than NASA's other orbiters and sometimes closer to Mars, so it crosses altitudes occupied by those orbiters. For safety, NASA also monitors positions of ESA's and India's orbiters, which both fly elongated orbits.

"Previously, collision avoidance was coordinated between the Odyssey and MRO navigation teams," said Robert Shotwell, Mars Program chief engineer at NASA's Jet Propulsion Laboratory, Pasadena, California. "There was less of a possibility of an issue. MAVEN's highly elliptical orbit, crossing the altitudes of other orbits, changes the probability that someone will need to do a collision-avoidance maneuver. We track all the orbiters much more closely now. There's still a low probability of needing a maneuver, but it's something we need to manage."



This graphic depicts the relative shapes and distances from Mars for five active orbiter missions plus the planet's two natural satellites. It illustrates the potential for intersections of the spacecraft orbits. Credit: NASA/JPL-Caltech.

Traffic management at Mars is much less complex than in Earth orbit, where more than 1000 active orbiters plus additional pieces of inactive hardware add to hazards. As Mars exploration intensifies, though, and will continue to do so with future missions, precautions are increasing. The new process was established to manage this growth as new members are added to the Mars orbital community in years to come. All five active Mars orbiters use the communication and tracking services of NASA's Deep Space Network, which is managed at JPL. This brings trajectory information together, and engineers can run computer projections of future trajectories out to a few weeks ahead for comparisons. "It's a monitoring function to anticipate when traffic will get heavy," said Joseph Guinn, manager of JPL's Mission Design and Navigation Section. "When two spacecraft are predicted to come too close to one another, we give people a heads-up in advance so the project teams can start coordinating about whether any maneuvers are needed."

The amount of uncertainty in the predicted location of a Mars orbiter a few days ahead is more than 2 kilometers (1.24 miles). Calculating projections for weeks ahead multiplies the uncertainty to dozens of kilometers (miles). In most cases when a collision cannot be ruled out from projections two weeks ahead, improved precision in the forecasting as the date gets closer will rule out a collision with no need for avoidance action. Mission teams for the relevant orbiters are notified in advance when projections indicate a collision is possible, even if the possibility will likely disappear in subsequent projections. This situation occurred on New Year's weekend, 2015.

On January 3, automated monitoring determined that two weeks later, MAVEN and MRO could come within about 3 kilometers (2 miles) of each other, with large uncertainties remaining in the exact passing distance. Although that was a Saturday, automatic messages went out to the teams operating the orbiters. "In this case, before the timeline got short enough to need to plan an avoidance maneuver, the uncertainties shrank, and that ruled out the chance of the two spacecraft coming too near each other," Guinn said. This is expected to be the usual pattern, with the advance warning kicking off higher-level monitoring and initial discussions about options.

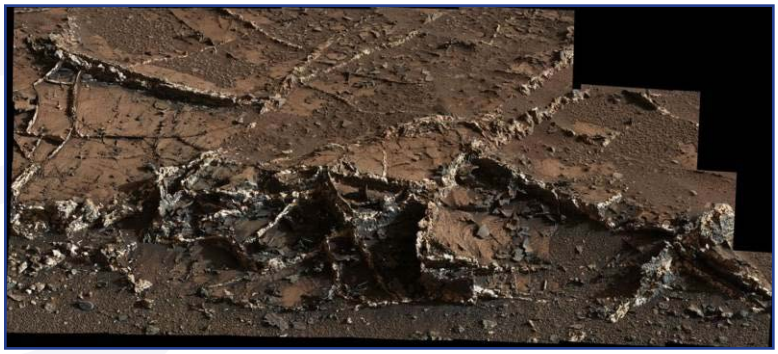
If preparations for an avoidance maneuver were called for, spacecraft commands would be written, tested, and approved for readiness, but such commands would not be sent to a spacecraft unless projections a day or two ahead showed probability of a hazardous conjunction. The amount of uncertainty about each spacecraft's exact location varies, so the proximity considered unsafe also varies. For some situations, a day-ahead projection of two craft coming within about 100 meters (100 yards) of each other could trigger a maneuver.

The new formal collision-avoidance process for Mars is part of NASA's Multi-Mission Automated Deep-Space Conjunction Assessment Process. A side benefit of it is that information about when two orbiters will be near each other — although safely apart — could be used for planning coordinated science observations. The pair could look at some part of Mars or its atmosphere from essentially the same point of view simultaneously with complementary instruments.

For more about NASA's Mars Exploration Program, visit *http://mars.jpl.nasa.gov* and *http://www.nasa.gov/mars*.

Curiosity Rover Eyes Prominent Mineral Veins on Mars

Two-tone mineral veins at a site NASA's Curiosity rover has reached by climbing a layered martian mountain offer clues about multiple episodes of fluid movement. These episodes occurred later than the wet environmental conditions that formed lake-bed deposits the rover examined at the mountain's base.



This March 18, 2015, view from the Mast Camera on NASA's Curiosity Mars rover shows a network of two-tone mineral veins at an area called "Garden City" on lower Mount Sharp. Credit: NASA/JPL-Caltech/MSSS.

Curiosity has analyzed rock samples drilled from three targets lower on the mountain in the past seven months. It found a different mineral composition at each, including a silica mineral named cristobalite in the most recent sample. These differences, together with the prominent veins seen in images taken a little farther uphill, illustrate how the layers of Mount Sharp provide a record of different stages in the evolution of the area's ancient environment.

The two-tone veins are at the site called "Garden City." They appear as a network of ridges left standing above the now eroded-away bedrock in which they formed. Individual ridges range up to about 6 centimeters (2.5 inches) high and half that in width, and they bear both bright and dark material.

"Some of them look like ice-cream sandwiches: dark on both edges and white in the middle," said Linda Kah, a Curiosity science team member at the University of Tennessee, Knoxville. "These materials tell us about secondary fluids that were transported through the region after the host rock formed."

Veins such as these form where fluids move through cracked rock and deposit minerals in the fractures, often affecting the chemistry of the rock surrounding the fractures. Curiosity has found bright veins composed of calcium sulfate at several previous locations. The dark material preserved here presents an opportunity to learn more. Kah said, "At least two secondary fluids have left evidence here. We want to understand the chemistry of the different fluids that were here and the sequence of events. How have later fluids affected the host rock?"

Some of the sequence is understood: Mud that formed lake-bed mudstones Curiosity examined near its 2012 landing site and after reaching Mount Sharp must have dried and hardened before the fractures formed. The dark material that lines the fracture walls reflects an earlier episode of fluid flow than the white, calcium-sulfate-rich veins do, although both flows occurred after the cracks formed.

Garden City is about 12 meters (39 feet) higher than the bottom edge of the "Pahrump Hills" outcrop of the bedrock forming the basal layer of Mount Sharp, at the center of Mars' Gale Crater. The Curiosity mission spent about six months examining the first 10 meters (33 feet) of elevation at Pahrump Hills, climbing from the lower edge to higher sections three times to vertically profile the rock structures and chemistry, and to select the best targets for drilling.

"We investigated Pahrump Hills the way a field geologist would, looking over the whole outcrop first to choose the best samples to collect, and it paid off," said David Blake of NASA's Ames Research Center, Moffett Field, California, principal investigator for the Chemistry and Mineralogy (CheMin) analytical laboratory instrument inside the rover.

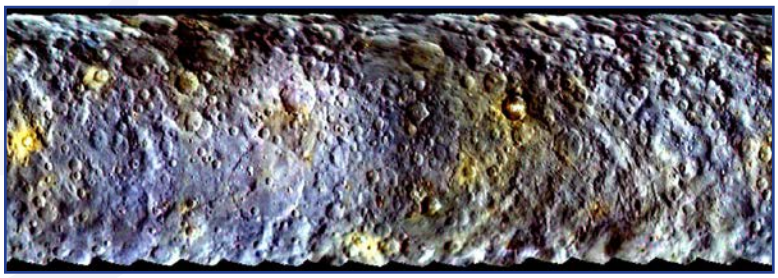
Analysis is still preliminary, but the three drilled samples from Pahrump Hills have clear differences in mineral ingredients. The first, "Confidence Hills," had the most clay minerals and hematite, both of which commonly form under wet conditions. The second, "Mojave," had the most jarosite, an oxidized mineral containing iron and sulfur that forms in acidic conditions. The third is "Telegraph Peak." Examination of Garden City has not included drilling a sample.

Blake said, "Telegraph Peak has almost no evidence of clay minerals, the hematite is nearly gone, and jarosite abundance is down. The big thing about this sample is the huge amount of cristobalite, at about 10% or more of the crystalline material." Cristobalite is a mineral form of silica. The sample also contains a small amount of quartz, another form of silica. Among the possibilities are that some process removed other ingredients, leaving an enrichment of silica behind; or that dissolved silica was delivered by fluid transport; or that the cristobalite formed elsewhere and was deposited with the original sediment.

For more information, visit *http://www.nasa.gov/msl* and *http://mars.jpl.nasa.gov/msl/*.

Dawn's Ceres Color Map Reveals Surface Diversity

A new color map of dwarf planet Ceres, which NASA's Dawn spacecraft has been orbiting since March, reveals the diversity of the surface of this planetary body. Differences in morphology and color across the surface suggest Ceres was once an active body, Dawn researchers said at the 2015 General Assembly of the European Geosciences Union in Vienna in April.



This map-projected view of Ceres was created from images taken by NASA's Dawn spacecraft during its initial approach to the dwarf planet, prior to being captured into orbit in March 2015. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA.

"This dwarf planet was not just an inert rock throughout its history. It was active, with processes that resulted in different materials in different regions. We are beginning to capture that diversity in our color images," said Chris Russell of the University of California, Los Angeles, principal investigator for the Dawn mission.

The Dawn mission made history on March 6 as the first spacecraft to reach a dwarf planet, and the first spacecraft to orbit two extraterrestrial targets. Previously, Dawn studied giant asteroid Vesta from 2011 to 2012, uncovering numerous insights about its geology and history. While Vesta is a dry body, Ceres is believed to be 25% water ice by mass. By comparing Vesta and Ceres, scientists hope to gain a better understanding of the formation of the solar system.

Ceres' surface is heavily cratered, as expected, but appears to have fewer large craters than scientists anticipated. More details are emerging as the spacecraft completes its first dedicated science mapping phase in June, from a distance of 4400 kilometers (2640 miles) from the surface, according to Martin Hoffmann, investigator on the Dawn framing camera team, based at the Max Planck Institute for Solar System Research, Göttingen, Germany.

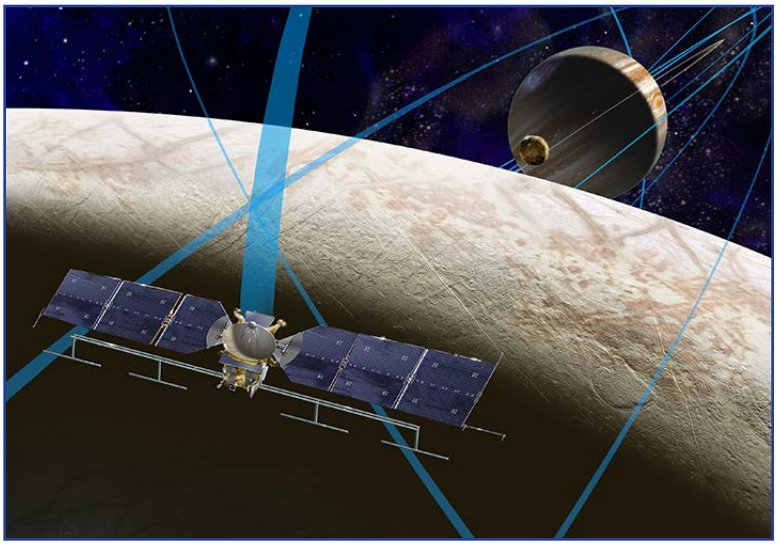
The visible and infrared mapping spectrometer (VIR), an imaging spectrometer that examines Ceres in visible and infrared light, has been examining the relative temperatures of features on Ceres' surface. Preliminary examination suggests that different bright regions on Ceres' surface behave differently, said Federico Tosi, investigator from the VIR instrument team at the Institute for Space Astrophysics and Planetology and the Italian National Institute for Astrophysics, Rome.

Based on observations from NASA's Hubble Space Telescope, planetary scientists have identified 10 bright regions on Ceres' surface. One pair of bright spots, by far the brightest visible marks on Ceres, appears to be located in a region that is similar in temperature to its surroundings. But a different bright feature corresponds to a region that is cooler than the rest of Ceres' surface. The origins of Ceres' bright spots, which have captivated the attention of scientists and the public alike, remain unknown. It appears the brightest pair is located in a crater 92 kilometers (57 miles) wide. As Dawn gets closer to the surface of Ceres, better-resolution images will become available. "The bright spots continue to fascinate the science team, but we will have to wait until we get closer and are able to resolve them before we can determine their source," Russell said.

Both Vesta and Ceres are located in the main asteroid belt between Mars and Jupiter. The Dawn spacecraft will continue studying Ceres through June 2016. For more information, visit *http://dawn.jpl.nasa.gov*.

NASA's Europa Mission Begins with Selection of Science Instruments

NASA has selected nine science instruments for a mission to Jupiter's moon Europa, to investigate whether the mysterious icy moon could harbor conditions suitable for life. NASA's Galileo mission yielded strong evidence that Europa, about the size of Earth's moon, has an ocean beneath a frozen crust of unknown thickness. If proven to exist, this global ocean could have more than twice as much water as Earth. With abundant salt water, a rocky sea floor, and the energy and chemistry provided by tidal heating, Europa could be the best place in the solar system to look for present day life beyond our home planet.



This artist's rendering shows a concept for a future NASA mission to Europa in which a spacecraft would make multiple close flybys of the icy jovian moon, thought to contain a global subsurface ocean. Credit: NASA/JPL-Caltech.

"Europa has tantalized us with its enigmatic icy surface and evidence of a vast ocean, following the amazing data from 11 flybys of the Galileo spacecraft over a decade ago and recent Hubble observations suggesting plumes of water shooting out from the moon," said John Grunsfeld, associate administrator for NASA's Science Mission Directorate in Washington. "We're excited about the potential of this new mission and these instruments to unravel the mysteries of Europa in our quest to find evidence of life beyond Earth." NASA's fiscal year 2016 budget request includes $30 million to formulate a mission to Europa. The mission would send a solar-powered spacecraft into a long, looping orbit around the gas giant Jupiter to perform repeated close flybys of Europa over a three-year period. In total, the mission would perform 45 flybys at altitudes ranging from 25 kilometers to 2700 kilometers (16 miles to 1700 miles).

The payload of selected science instruments includes cameras and spectrometers to produce high-resolution images of Europa's surface and determine its composition. An ice-penetrating radar will determine the thickness of the moon's icy shell and search for subsurface lakes similar to those beneath Antarctica. The mission also will carry a magnetometer to measure strength and direction of the moon's magnetic field, which will allow scientists to determine the depth and salinity of its ocean. A thermal instrument will scour Europa's frozen surface in search of recent eruptions of warmer water, while additional instruments will search for evidence of water and tiny particles in the moon's thin atmosphere. NASA's Hubble Space Telescope observed water vapor above the south polar region of Europa in 2012, providing the first strong evidence of water plumes. If the plumes' existence is confirmed — and they're linked to a subsurface ocean — it will help scientists investigate the chemical makeup of Europa's potentially habitable environment while minimizing the need to drill through layers of ice.

Last year, NASA invited researchers to submit proposals for instruments to study Europa. Thirty-three were reviewed and, of those, nine were selected for a mission that will launch in the 2020s. "This is a giant step in our search for oases that could support life in our own celestial backyard," said Curt Niebur, Europa program scientist at NASA Headquarters in Washington. "We're confident that this versatile set of science instruments will produce exciting discoveries on a much-anticipated mission."

The NASA selectees are:

Plasma Instrument for Magnetic Sounding (PIMS) — principal investigator Dr. Joseph Westlake of Johns Hopkins Applied Physics Laboratory (APL), Laurel, Maryland. This instrument works in conjunction with a magnetometer and is key to determining Europa's ice shell thickness, ocean depth, and salinity by correcting the magnetic induction signal for plasma currents around Europa.

Interior Characterization of Europa using Magnetometry (ICEMAG) — principal investigator Dr. Carol Raymond of NASA's Jet Propulsion Laboratory (JPL), Pasadena, California. This magnetometer will measure the magnetic field near Europa and — in conjunction with the PIMS instrument — infer the location, thickness and salinity of Europa's subsurface ocean using multi-frequency electromagnetic sounding.

Mapping Imaging Spectrometer for Europa (MISE) — principal investigator Dr. Diana Blaney of JPL. This instrument will probe the composition of Europa, identifying and mapping the distributions of organics, salts, acid hydrates, water ice phases, and other materials to determine the habitability of Europa's ocean.

Europa Imaging System (EIS) — principal investigator Dr. Elizabeth Turtle of APL. The wide and narrow angle cameras on this instrument will map most of Europa at 164 foot (50 meter) resolution, and will provide images of areas of Europa's surface at up to 100 times higher resolution.

Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) — principal investigator Dr. Donald Blankenship of the University of Texas, Austin. This dual-frequency ice penetrating radar instrument is designed to characterize and sound Europa's icy crust from the near-surface to the ocean, revealing the hidden structure of Europa's ice shell and potential water within.

Europa Thermal Emission Imaging System (E-THEMIS) — principal investigator Dr. Philip Christensen of Arizona State University, Tempe. This "heat detector" will provide high spatial resolution, multi-spectral thermal imaging of Europa to help detect active sites, such as potential vents erupting plumes of water into space.

MAss SPectrometer for Planetary EXploration/Europa (MASPEX) — principal investigator Dr. Jack (Hunter) Waite of the Southwest Research Institute (SwRI), San Antonio. This instrument will determine the composition of the surface and subsurface ocean by measuring Europa's extremely tenuous atmosphere and any surface material ejected into space.

Ultraviolet Spectrograph/Europa (UVS) — principal investigator Dr. Kurt Retherford of SwRI. This instrument will adopt the same technique used by the Hubble Space Telescope to detect the likely presence of water plumes erupting from Europa's surface. UVS will be able to detect small plumes and will provide valuable data about the composition and dynamics of the moon's rarefied atmosphere.

SUrface Dust Mass Analyzer (SUDA) — principal investigator Dr. Sascha Kempf of the University of Colorado, Boulder. This instrument will measure the composition of small, solid particles ejected from Europa, providing the opportunity to directly sample the surface and potential plumes on low-altitude flybys.

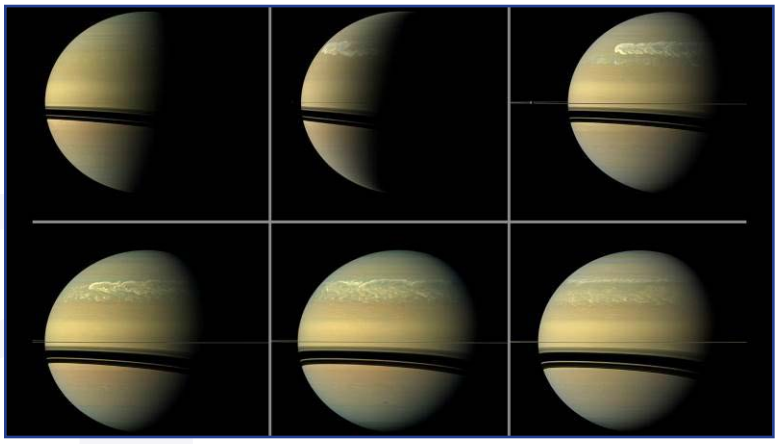
Separate from the selectees listed above, the SPace Environmental and Composition Investigation near the Europan Surface (SPECIES) instrument has been chosen for further technology development. Led by principal investigator Dr. Mehdi Benna at NASA's Goddard Space Flight Center in Greenbelt, Maryland, this combined neutral mass spectrometer and gas chromatograph will be developed for other mission opportunities.

For more information, visit *http://europa.jpl.nasa.gov/*.

NASA-Funded Study Explains Saturn's Epic Tantrums

The long-standing mystery of why Saturn seethes with enormous storms every 30 years may have been solved by scientists working with data from NASA's Cassini mission. The tempests, which can grow into bright bands that encircle the entire planet, are on a natural timer that is reset by each subsequent storm, the researchers report. In 140 years of telescope observations, great storms have erupted on Saturn six times. Cassini and observers on Earth tracked the most recent of these storms from December 2010 to August 2011. During that time, the storm exploded through the clouds, eventually winding its way around Saturn.

In a paper published online in April in the journal *Nature Geoscience*, scientists describe the effect they believe is responsible for the periodic outbursts. The basic idea is that water vapor is heavier than the hydrogen and helium that make up the bulk of Saturn's atmosphere, so once each giant storm dumps its huge mass of rain, the air within the clouds is left lighter than the atmosphere below. For a time, this situation shuts off the process of convection — in which warm, moist air rises, and cool, dense air sinks — that creates new clouds and storms.



This series of images from NASA's Cassini spacecraft shows the development of a huge storm of the type that erupts about every 30 years on Saturn. Credit: NASA/JPL-Caltech/SSI.

"For decades after one of these storms, the warm air in Saturn's deep atmosphere is too wet, and too dense, to rise," said Cheng Li, a graduate student at the California Institute of Technology in Pasadena, who led the study. "The air above has to cool off, radiating its heat to space, before its density is greater than that of the hot, wet air below. This cooling process takes about 30 years, and then come the storms."

Li thinks the episodic nature of the storms indicates Saturn's deep atmosphere contains more water, relative to the other atmospheric constituents, than Jupiter. The researchers suggest Saturn's extra-wet

interior might explain why the planet has such epic tantrums, whereas Jupiter does not. If Saturn's deep atmosphere were drier, scientists would expect continuous, smaller storms, as observed on Jupiter, Li said. Instead, Saturn's outbursts are episodic and quite explosive.

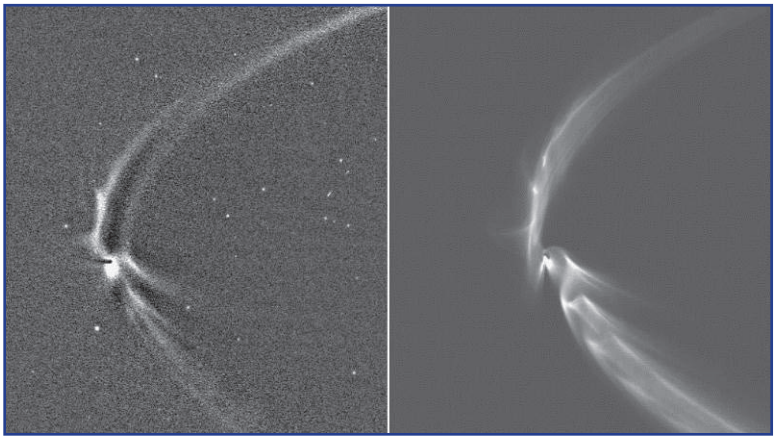
Other observations by ground- and spacebased telescopes have hinted at a wet interior for Saturn. "Previous studies using spectroscopy have shown that Saturn's interior is enriched in methane and other volatiles, by two or three times, compared to Jupiter. From there, it's a short leap to expect that Saturn is also rich in oxygen, which is also a volatile and a big part of every H_2O molecule," said Andrew Ingersoll, a member of the Cassini science team, also at Caltech, who co-authored the paper with Li. Volatiles are elements and chemical compounds that change from solid to liquid or gas at relatively low temperatures.

Scientists are interested in understanding the amount of oxygen and other volatile ingredients in Saturn and Jupiter. These ingredients provide important clues about the formation of the two planets — which are thought to have formed before all the others — and conditions in the early solar system. For more information, visit *http://www.nasa.gov/cassini* and *http://saturn.jpl.nasa.gov*.

Icy Tendrils Reaching into Saturn Ring Traced to Their Source

Long, sinuous, tendril-like structures seen in the vicinity of Saturn's icy moon Enceladus originate directly from geysers erupting from its surface, according to scientists studying images from NASA's Cassini spacecraft. This result was published online on April 14 in a study in the *Astronomical Journal*, along with additional insights into the nature of the structures.

"We've been able to show that each unique tendril structure can be reproduced by particular sets of geysers on the moon's surface," said Colin Mitchell, a Cassini imaging team associate at the Space Science Institute in Boulder, Colorado, and lead author of the paper. Mitchell and colleagues used computer simulations to follow the trajectories of ice grains ejected from individual geysers. The geysers, which were discovered by Cassini in 2005, are jets of tiny water ice particles, water vapor, and simple organic compounds.



This collage, consisting of two Cassini images of long, sinuous, tendril-like features from Saturn's moon Enceladus and two corresponding computer simulations of the same, illustrates how well the structures, and the sizes of the particles composing them, can be modeled by tracing the trajectories of tiny, icy grains ejected from Enceladus' south polar geysers. Credit: NASA/JPL-Caltech/Space Science Institute.

Under certain lighting conditions, Cassini's wide-view images showing icy material erupting from Enceladus reveal faint, finger-like features, dubbed "tendrils" by the imaging team. The tendrils reach into Saturn's E ring — the ring in which Enceladus orbits — extending tens of thousands of kilometers (or miles) away from the moon. Since the tendrils were discovered, scientists

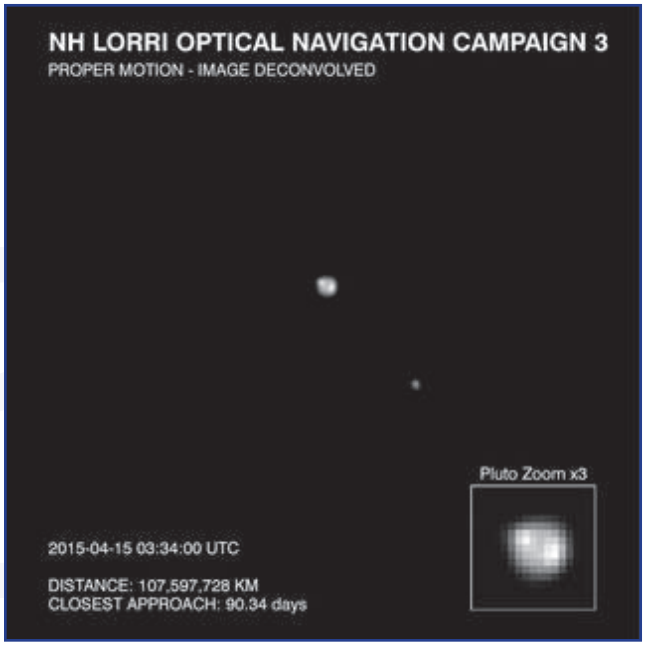
have thought they were the result of the moon's geysering activity and the means by which Enceladus supplies material to the E ring. But the ghostly features had never before been traced directly to geysers on the surface.

Because the team was able to show that tendril structures of different shapes correspond to different sizes of geyser particles, the team was able to zero in on the sizes of the particles forming them. They found the tendrils are composed of particles with diameters no smaller than about a hundred thousandth of an inch, a size consistent with the measurements of E-ring particles made by other Cassini instruments.

As the researchers examined images from different times and positions around Saturn, they also found that the detailed appearance of the tendrils changes over time. "It became clear to us that some features disappeared from one image to the next," said John Weiss, an imaging team associate at Saint Martin's University in Lacey, Washington, and an author on the paper. The authors suspect that changes in the tendrils' appearance likely result from the cycle of tidal stresses — squeezing and stretching of the moon as it orbits Saturn — and its control of the widths of fractures from which the geysers erupt. The stronger the tidal stresses raised by Saturn at any point on the fractures, the wider the fracture opening and the greater the eruption of material. The authors will investigate in future work whether this theory explains the tendrils' changing appearance.

For more information, visit *http://www.nasa.gov/cassini* and *http://saturn.jpl.nasa.gov/*.

NASA's New Horizons Detects Surface Features, Possible Polar Cap on Pluto



This image of Pluto and its largest moon, Charon, was taken by the Long Range Reconnaissance Imager (LORRI) on NASA's New Horizons spacecraft on April 15, 2015. The image is part of several taken between April 12 and 18. Credit: NASA/JHU-APL/SwRI.

For the first time, images from NASA's New Horizons spacecraft are revealing bright and dark regions on the surface of faraway Pluto — the primary target of the New Horizons close flyby in mid-July. The images were captured in early to mid-April from within 113 million kilometers (70 million miles), using the telescopic Long-Range Reconnaissance Imager (LORRI) camera on New Horizons. A technique called image deconvolution sharpens the raw, unprocessed images beamed back to Earth. New Horizons scientists interpreted the data to reveal the dwarf planet has broad surface markings — some bright, some dark — including a bright area at one pole that may be a polar cap.

"As we approach the Pluto system we are starting to see intriguing features such as a bright region near Pluto's visible pole, starting the great scientific adventure to understand this enigmatic celestial object," says John Grunsfeld, associate

administrator for NASA's Science Mission Directorate in Washington. "As we get closer, the excitement is building in our quest to unravel the mysteries of Pluto using data from New Horizons."

Also captured in the images is Pluto's largest moon, Charon, rotating in its 6.4-day-long orbit. The exposure times used to create this image set — a tenth of a second — were too short for the camera to detect Pluto's four much smaller and fainter moons.

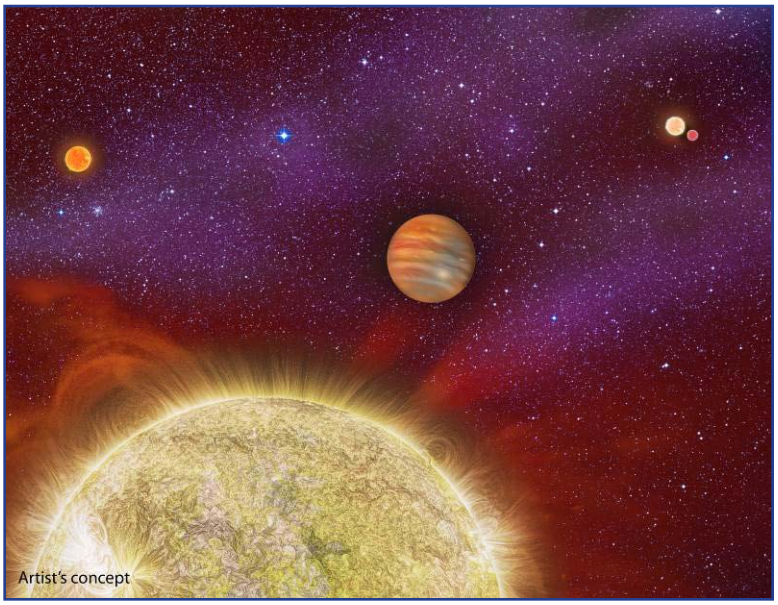
Since it was discovered in 1930, Pluto has remained an enigma. It orbits our Sun about 5 billion kilometers (more than 3 billion miles) from Earth, and researchers have struggled to discern any details about its surface. These latest New Horizons images allow the mission science team to detect clear differences in brightness across Pluto's surface as it rotates.

"After traveling more than nine years through space, it's stunning to see Pluto, literally a dot of light as seen from Earth, becoming a real place right before our eyes," said Alan Stern, New Horizons principal investigator at Southwest Research Institute (SwRI) in Boulder, Colorado. "These incredible images are the first in which we can begin to see detail on Pluto, and they are already showing us that Pluto has a complex surface." The images the spacecraft returns will dramatically improve as New Horizons speeds closer to its July rendezvous with Pluto.

"We can only imagine what surprises will be revealed when New Horizons passes approximately 12,500 kilometers (7800 miles) above Pluto's surface this summer," said Hal Weaver, the mission's project scientist at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland. For more information, visit *http://www.nasa.gov/newhorizons* and *http://pluto.jhuapl.edu/*.

Planet "Reared" by Four Parent Stars

Growing up as a planet with more than one parent star has its challenges. Although the planets in our solar system circle just one star, our Sun, other more distant planets, called exoplanets, can be reared in families with two or more stars. Researchers wanting to know more about the complex influences of multiple stars on planets have come up with two new case studies: a planet found to have three parents, and another with four.



This artist's concept shows the 30 Ari system, which includes four stars and a planet. Credit: Karen Teramura, UH IfA.

The discoveries were made using instruments fitted to telescopes at the Palomar Observatory in San Diego: the Robo-AO adaptive optics system, developed by the Inter-University

Center for Astronomy and Astrophysics in India and the California Institute of Technology (Caltech), and the PALM-3000 adaptive optics system, partially funded by NASA and developed by NASA's Jet Propulsion Laboratory (JPL) and Caltech.

This is only the second time a planet has been identified in a quadruple star system. While the planet was known before, it was thought to have only three stars, not four. The first four-star planet, KIC 4862625, was discovered in 2013 by citizen scientists using public data from NASA's Kepler mission.

The latest discovery suggests that planets in quadruple star systems might be less rare than once thought. In fact, recent research has shown that this type of star system, which usually consists of two pairs of twin stars slowly circling each other at great distances, is itself more common than previously believed. "About 4% of solar-type stars are in quadruple systems, which is up from previous estimates because observational techniques are steadily improving," said co-author Andrei Tokovinin of the Cerro Tololo Inter-American Observatory in Chile.

The newfound four-star planetary system, called 30 Ari, is located 136 light-years away in the constellation Aries. The system's gaseous planet is enormous, with 10 times the mass of Jupiter, and it orbits its primary star every 335 days. The primary star has a relatively close partner star, which the planet does not orbit. This pair, in turn, is locked in a long-distance orbit with another pair of stars about 1670 astronomical units (AU) away (an astronomical unit is the distance between Earth and the Sun). Astronomers think it's highly unlikely that this planet, or any moons that might circle it, could sustain life.

Were it possible to see the skies from this world, the four parent stars would look like one small Sun and two very bright stars that would be visible in daylight. One of those stars, if viewed with a large enough telescope, would be revealed to be a binary system, or two stars orbiting each other.

In recent years, dozens of planets with two or three parent stars have been found, including those with "Tatooine" sunsets reminiscent of the Star Wars movies. Finding planets with multiple parents isn't too much of a surprise, considering that binary stars are more common in our galaxy than single stars. "Star systems come in myriad forms. There can be single stars, binary stars, triple stars, even quintuple star systems," said Lewis Roberts of JPL, lead author of the new findings appearing in the *Astronomical Journal*. "It's amazing the way nature puts these things together."

For more information, visit *http://www.astro.caltech.edu/palomar* and *http://planetquest.jpl.nasa.gov*.

"Spotlight on Education" highlights events and programs that provide opportunities for planetary scientists to become involved in education and public outreach and to engage science educators and the community. If you know of space science educational programs or events that should be included, please contact the Lunar and Planetary Institute's Education Department at shupla@lpi.usra.edu.

Upcoming Public Event Opportunities

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

New Horizons Reaches Pluto —

The New Horizons mission will fly past this mysterious icy dwarf planet on July 14, 2015. Information and resources for your Pluto celebrations are available at *http://pluto.jhuapl.edu*.

International Observe the Moon Night (InOMN) —

International Observe the Moon Night (InOMN) is an annual worldwide public event, to be held on September 19 in 2015, that encourages observation, appreciation, and understanding of our Moon and its connection to NASA planetary science and exploration. Everyone is invited to join the celebration by hosting or attending an InOMN event. More information is available at *http://observethemoonnight.org/*.

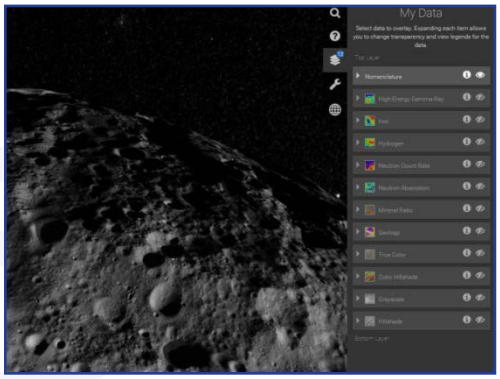
Eugene Shoemaker Impact Cratering Award

The Eugene M. Shoemaker Impact Cratering Award is for undergraduate or graduate students, of any nationality, working in any country, in the disciplines of geology, geophysics, geochemistry, astronomy, or biology. The award, which will include $2500, is to be applied for the study of impact craters, either on Earth or on the other solid bodies in the solar system, which areas of study may include but shall not necessarily be limited to impact cratering processes, the bodies that make the impacts, or the geological, chemical, or biological results of impact cratering. The application deadline is **September 11, 2015**. For more information, visit *http://www.lpi.usra.edu/science/kring/Awards/Shoemaker_Award/*.

American Astronomical Society Education Prize

The AAS Education Prize is to recognize outstanding contributions to the education of the public, students, and/or the next generation of professional astronomers. Nominations and letters of support

for the AAS prizes for 2015 must arrive in the Secretary's office by **June 30, 2015**. Information about submitting a nomination is available at *http://aas.org/grants-and-prizes/prize-nominations*.

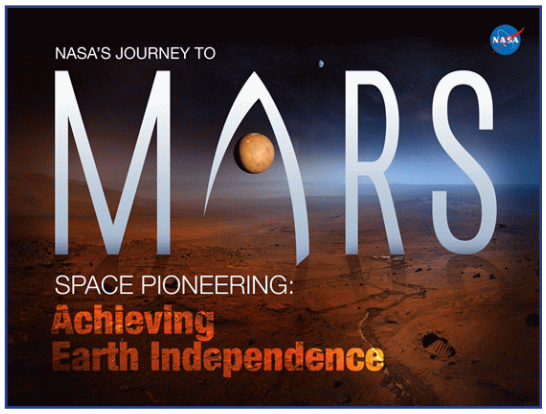


Tool Enabling Citizen Scientists to Examine Asteroid Vesta

NASA has announced the release of Vesta Trek, a free, web-based application that provides detailed visualizations of Vesta, a large asteroid studied by the Dawn mission. The application includes interactive maps, 3-D printer-exportable topography, and standard keyboard gaming controls to maneuver a first-person visualization of "flying" across the surface of the asteroid. For more information, visit *http://vestatrek.jpl.nasa.gov/*.

NASA's Journey to Mars Challenge

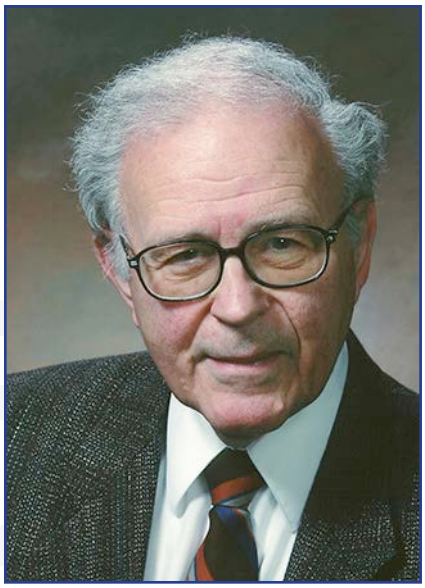
As NASA embarks on an ambitious journey to Mars, the agency is looking for innovative and creative ideas to help make the journey possible! The public is invited to share their ideas, in detail, for developing the elements of space pioneering necessary to establish a continuous human presence on the Red Planet. These ideas could include shelter, food, water, breathable air, communication, exercise, social interactions, and medicine, but NASA encourages participants to consider elements beyond these examples.



NASA will judge submissions on relevance, creativity, simplicity, resource efficiency, feasibility, comprehensiveness, and scalability. NASA expects to make up to three awards at a minimum of $5000 each from a total award pool of $15,000. Entries are due **July 6, 2015**. For more information about the challenge, visit *https://www.innocentive.com/ar/challenge/9933746*.

Ride Along with the New Horizons Spacecraft

"Eyes on the Solar System" is a 3-D environment full of real NASA mission data. The New Horizons mission is about to fly past Pluto, and a Pluto module of the Eyes on the Solar System interactive software is now live at *http://eyes.nasa.gov/pluto*. In Preview mode, choose the instrument through whose aperture you wish to look. Or, choose Telescope mode to see where to look for Pluto from near your own location.



Robert P. Kraft, 1927–2015

Dr. Robert Paul Kraft died from complications of aspiration pneumonia due to a stroke on May 26, 2015. A prominent astronomer and former director of the University of California Observatories and a professor emeritus of astronomy and astrophysics at the University of California (UC) Santa Cruz, Kraft was 87 years old.

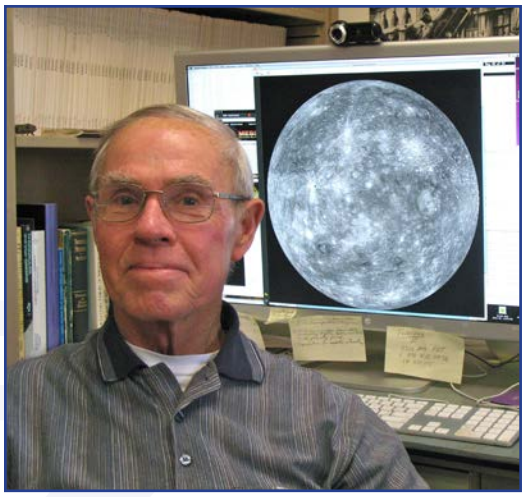
Born and raised in Seattle, Washington, Kraft earned B.S. and M.S. degrees in mathematics from the University of Washington and a Ph.D. in astronomy from UC Berkeley. He held faculty positions at Indiana University and the University of Chicago in the 1950s, then rose to prominence in the 1960s as an astronomer at the Mt. Wilson and Palomar Observatories in Pasadena. A widely recognized researcher, Kraft was also a gifted administrator who helped guide astronomy into the modern era. He joined the astronomy faculty at UC Santa Cruz and Lick Observatory in 1967. After two appointments as acting director, he was named director of Lick Observatory in 1981 and became director of the newly created UC Observatories in 1988. In that position, he oversaw both Lick Observatory and UC's role in building the state-of-the-art W. M. Keck Observatory in Hawaii.

Kraft played a key role in bringing about the Keck Observatory, committing the resources of Lick and UC to the construction and instrumentation of the world's first 10-meter telescope, now known as Keck I. Keck I and its twin, Keck II, are among the largest optical and infrared telescopes ever built. UC Observatories, which he directed until 1991, now operates Lick Observatory, manages the Keck Observatory in cooperation with Caltech and NASA, and oversees UC's participation in the Thirty Meter Telescope project.

Kraft also served as president of the American Astronomical Society from 1974 to 1976 and president of the International Astronomical Union from 1997 to 2000. As a researcher, Kraft made important contributions to the understanding of novae, stars that undergo a sudden increase in brightness due to massive nuclear explosions. He showed that all novae arise from close binary star systems in which one star (usually a white dwarf) siphons off hydrogen and helium from its companion, leading to an explosion. Kraft also established an important rung on the ladder of celestial distances by assessing the contribution of interstellar dust to the dimming of Cepheid variables in the disk of our galaxy. His work on stellar rotation showed that stars like the Sun spin slower and slower as they age because winds of charged particles carry away their angular momentum. He later turned his attention to the chemical composition of stars in the Milky Way.

Kraft was elected to the National Academy of Sciences in 1971 and the American Academy of Arts and Sciences in 1973. In 1995, the American Astronomical Society named Kraft the Henry Norris Russell Lecturer in recognition of lifetime achievement in astronomy. He received the Astronomical Society of the Pacific's highest honor, the Catherine Wolfe Bruce Gold Medal, in 2005.

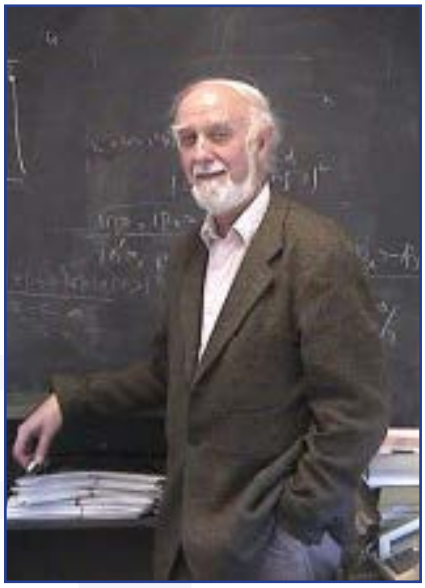
— Text courtesy of the University of California, Santa Cruz



Stanton J. Peale, 1937–2015

Stanton J. Peale passed away on May 14, 2015, in Santa Barbara from complications of leukemia. He was a kind and brilliant planetary scientist with expertise in dynamics and geophysics. After earning his Ph.D. at Cornell University in 1965, he took a faculty position at the University of California, Los Angeles, and then at the University of California, Santa Barbara, where he worked from 1968 until 2015.

Peale's most recent work was submitted for publication on May 11, 2015. His contributions include the prediction of widespread volcanism on Jupiter's moon Io, the derivation of a general theoretical framework that governs the rotational states of bodies subject to tides, the study of tidal evolution in satellite systems, and the development of an ingenious procedure to determine the size and state of Mercury's core. He was also a pioneer in the study of extrasolar planets, both in terms of their dynamics and their detection by microlensing. He was awarded the Newcomb Cleveland Prize (1979), the James Craig Watson Medal (1982), and the Brouwer Award (1992), and was elected to the National Academy of Sciences in 2009.



Alexander Dalgarno, 1928–2015

Alexander Dalgarno, renowned astronomer and mathematician, passed away peacefully on April 9. Born in 1928 and raised in London, he studied mathematics and theoretical atomic physics at University College London. He became a professor at the Queen's University of Belfast and later joined Harvard University's Astronomy Department in 1967, served as its chairman, and became the Phillips Professor of Astronomy.

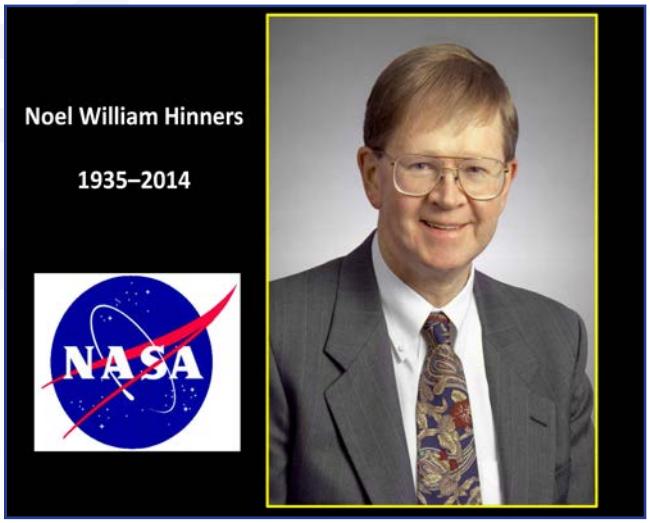
Dalgarno has been referred to as the "father of molecular astrophysics." His major contributions to the understanding of fundamental atomic and molecular processes enabled him to develop diagnostics of the physical conditions of atmospheres and astrophysical sources and to elucidate the roles of such processes in controlling those environments. He greatly influenced the research of physicists, chemists, atmospheric scientists, and astronomers. Dalgarno established the influential Institute for Theoretical Atomic and Molecular Physics at the Harvard-Smithsonian Center for Astrophysics. He was a recipient of many awards, including the Benjamin Franklin Medal in Physics, the Royal Society's Hughes Medal, the Royal Astronomical Society's Gold Medal, the American Geophysical Society's Fleming Medal, and the Royal Society of Chemistry's Spiers Medal. He even had an asteroid named after him. He was a gifted mentor to generations of students, a generous and inspiring colleague, and a humanist in every respect.

— Portions of text courtesy of the Division for Planetary Sciences

Tribute to Noel William Hinners, 1935–2014

— James W. Head III, Brown University

Editor's Note: The following text reflects a special presentation given by Jim Head during the 46th Lunar and Planetary Science Conference, held in March of this year. A video of the presentation is available on the LPSC website, http://www.hou.usra.edu/meetings/lpsc2015.



Noel Hinners passed away last year after an illustrious career in planetary and space science. A few of you may have known Noel, many of you may have heard of him, but many more may not know at all who he was. But Noel touched all of our lives, personal and professional, and everyone in this room owes him a *huge* debt of gratitude.

I knew Noel very well. He was my first boss when, fresh out of graduate school in 1968, I came to work at NASA Headquarters for the Apollo Lunar Exploration Program, doing site selection, astronaut training and mission operations.

Who was Noel Hinners and what is his legacy? In his youth growing up in New Jersey, Noel had a passionate interest in, well, chicken farming. He went to Rutgers University, where he studied agricultural research and soil chemistry. Becoming interested in geology, he then went to Caltech where he got his Masters in Geochemistry. And then on to Princeton, where he got his Ph.D. in Geophysics and Geochemistry, doing his thesis on ore-forming fluids under Dick Holland.

From 1963 to 1972 Noel worked at NASA Headquarters for the Apollo Lunar Exploration Program (Bellcomm) doing Landing Site Selection and Mission Operations studies and activities. Noel was a passionate advocate for getting science into the core of the Apollo program: During this time, a small group of scientists known as the Four Horseman — Jerry Wasserburg, Bob Walker, Jim Arnold, and Paul Gast — provided the scientific and intellectual *pressure* to enable positive decisions to be made. Noel was their inside man, working relentlessly and very successfully to enable science in the Apollo Lunar Exploration Program.

Following Apollo, Noel became:

1972–1974: Director of the NASA Lunar Programs Office

1974–1979: NASA Associate Administrator for Space Science

1979–1982: Director of the National Air and Space Museum, Smithsonian Institution

1982–1987: Center Director at NASA Goddard Space Flight Center

1987–1989: NASA Associate Deputy Administrator and Chief Scientist

At the end of his NASA career, reflecting on his youth in New Jersey as an aspiring chicken farmer, Noel said: "Of course, that's why I was in space program administration, with so many turkeys and chickens."

From 1989 to 2002 Noel served as Vice President, Flight Systems, Lockheed-Martin Space Systems Company, where he was involved in Mars Surveyor, MRO, Stardust, and Genesis.

Noel served on various activities of the National Research Council Space Studies Board from 1981 to 1982 and 1989 to 1996 and chaired its Committee on Human Exploration.

Noel was a passionate advocate for both robotic AND human exploration: He observed that, "You don't transmit the human spirit through an antenna. You need to BE there, IN place, IN person."

The *New York Times* called Noel "The main advocate for pure scientific research in an organization ruled by rocket engineers and pilots."

Well, what is it like to be a scientist in space program administration in an organization ruled by rocket engineers and pilots?

Let me briefly share with you some of the questions and comments I have personally heard from some of those senior administrators, rocket engineers, and pilots during my career:

- "Jim, Do we really need any more Moon rocks?" (This was during Apollo 12, by the way!)
- "Do we really need a NASA sample handing facility? Let's give the rocks to the Smithsonian."
- Here's another one I got at the end of the Apollo program: "Jim, NASA is an engineering agency. Why don't we just give all the Moon rocks and data to the National Science Foundation and let them handle funding the science? We'll fly the missions."
- Here's a question I got while Noel and I were on President Reagan's Transition Team: "Why don't we shut down JPL?! Do we really need it? We could save some money here!"

Now these may sound like idiotic questions to us scientists, but they are *not*! These are the kinds of questions that are often asked at very high levels at Congress, NASA, OMB, OSTP, and other agencies. And they typically are not being asked of practicing scientists, but of scientific administrators, such as Noel Hinners. And without quick, articulate, and reasoned answers by people like Noel, the whole trend of scientific inquiry, and well-built infrastructures, can be terminated or diverted in a matter of minutes.

How did Noel respond to such questions at these high levels? In the words of Caltech legend Jerry Wasserburg: "Noel was never a governmental 'functionary.' He was always in love with good science, sought to identify it, aided and abetted it. He took joy in its successes. In the many conversations that we have had, his first question was always-'Tell me what is new and exciting in your scientific work?' 'Oh, that's wonderful! Where does it lead to now?' Noel was not a direct participant in the scientific action. He made it happen! That was his delight and pleasure. He sought to make these advances possible in the complex mess of money, politics, turf struggles and 'selling of the goods' to the powers and people who run things. His boyish charm carried him through many a difficult meeting or testimony to the Congress.'

Noel guided NASA through the relentless budget cuts of the 1970s and 1980s. In these really negative fiscal times, Noel ensured that the Lunar Receiving Laboratory and Curatorial Facility were built and funded, that there was a sample analysis and Apollo data analysis program, and that NASA integrated science and exploration to optimize the scientific return.

Why do we have the Hubble Space Telescope? In 1976, despite the success of Viking, Congress was coming down very heavily on NASA's budget and it was unlikely that the Space Telescope would survive. What did Noel, as Associate Administrator for Space Science, do?? He zeroed it out of the President's budget submitted to Congress. In Noel's words, "I figured in my own little head that to get the astronomy community energized, we would be better off zeroing it out." The community was so "energized" that they got Congress to add FULL funding back into the budget. Noel added: "Voila! It worked!"

One day when I saw someone coming out of Noel's office, I asked, "Who was that?" Noel said, "That was so and so from AGU. I had this idea to start a journal with a short turnaround time. We're going to call it *Geophysical Research Letters*. What do you think of that name?" If you see a need, do it! Noel never really wrote a single scientific research paper; but he *enabled all of you in the room to do just that*!

What kind of a person was Noel?

- Noel thought about others, not himself.
- In adversity he saw not frustration, but opportunity.
- In youth he saw not immaturity, but promise.
- His vision was firmly fixed on the *goals*, not the *milestones*.
- The deliverables were definitely a *means* to an end, not an end in themselves.
- He listened very carefully, but spoke with enthusiasm and passion for what he believed.
- He was the most amazing and nonconfrontational person that I have ever known, yet at the same time the most effective at winning hearts and minds in the huge high-stakes poker game of enabling space science.
- He *created* opportunities for all of us.

So what is Noel Hinners' legacy? You are looking at it *here in this room*! The robust and exciting discipline of planetary and space science, built from scratch!! Built on a solid foundation of facilities, fiscal resources, intellectual resources and leadership, exciting professional meetings, and a continuing string of accomplishments that excite people of all ages and galvanize young people to choose careers in science and engineering.

What would Noel, himself, say of his legacy? He would answer that question with a series of questions of his own: "What's new? What's exciting? Where should we be going? What do we need, to prepare for the next 20 years?" With Noel, it was *not* about the past, but about the *future*. Armed with answers to his questions, Noel would then say, in the words of Captain Jean Luc Picard, "Make it so!," with his enthusiasm and his boyish charm.

Let's celebrate the life of Noel W. Hinners by recognizing and supporting people like him, our planetary and space science leadership. As with Noel, these are the individuals who *enable* our science. And even more importantly, we can encourage young people to go into similar careers of enabling the most amazing exploration endeavor and scientific discipline in a millennium.

And it is OUR responsibility as practicing scientists to give our present and upcoming leaders good ideas about the future, so that they can indeed, as Noel Hinners did, "Make it So."

Barringer Award Recipients Announced

The Lunar and Planetary Institute (LPI) is pleased to announce the names of the students whose research will be supported by The Barringer Family Fund for Meteorite Impact Research. The 2015 awardees are Rebecca Greenberger (Brown University), Audrey Horne (Arizona State University), Alexandra Pontefract (University of Western Ontario, Canada), Kathryn Rathbun (University of Iowa), Rudolf Valja (University of Tartu, Estonia), and Verma Ankit Kumar (Trinity College, Ireland).

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.

ExMASS Research Program Announces Student Winners

The Center for Lunar Science and Exploration (CLSE), a member of the NASA Solar System Exploration Research Virtual Institute (SSERVI), has concluded the first year of the Exploration of the Moon and Asteroids by Secondary Students (ExMASS) program. The ExMASS program supports student scientists in their quest to understand the Moon and asteroids, as they are immersed in the process of science and exposed to science careers. The program's predecessor, the High School Lunar Research Projects, supported lunar research conducted by high school students from 2009 to 2013. This year, 11 high school teams, comprising 43 students from across the nation, embarked on a standards-based, data-rich, authentic lunar/asteroid science research project that aligns with CLSE research objectives and the National Research Council science priorities.

Bellaire High School students Sue Anne Davis, Kevin Nguyen, Jennifer Wang, Afton Widdershins, and Steven Zhou-Wright presented their research, entitled "Hypothesizing Existence of Zhuque Family in the 5:2 Kirkwood Gap," to a panel of planetary scientists. Their project ranked highest on presentation and research among all competing schools. As a result of their top score, the students and their teacher, Jimmy Newland, are invited to attend and present their research at the NASA Exploration Science Forum at NASA Ames Research Center in July 2015. The team's mentor was Dr. Maitrayee Bose of Arizona State University.

NASA Names Winners of Student Launch Challenge

For the third year in a row, Vanderbilt University of Nashville, Tennessee has been named the winning team in the NASA Student Launch challenge, earning the $5000 prize. The prize purse for the challenge, which took place on April 11, was provided by corporate sponsor Orbital ATK of Promontory, Utah. Teams from the University of Louisville, Kentucky, and the University of North Carolina, Charlotte, won second and third place, respectively. The 2015 Rookie of the Year award was presented to the University of Massachusetts, Boston.

Vanderbilt University of Nashville, Tennessee, won top prize in the 2015 NASA Student Launch challenge near NASA Marshall's Space Flight Center in Huntsville, Alabama. Credit: NASA/MSFC/Emmett Given.

Student Launch is a competitive learning opportunity for teams of students from middle school to university level to conduct research and development in rocket propulsion systems. Students spend eight months designing, building, and testing small high-powered rockets, scientific payloads, and/or ground support equipment using the same launch criteria as NASA.

"Student Launch enables teams to research innovative solutions to technical problems, which could potentially advance future NASA missions," said Tammy Rowan, manager of the Academic Affairs Office at NASA's Marshall Space Flight Center in Huntsville, Alabama. "Students demonstrate advanced concepts of 3-D printing, carbon-fiber engineering, and autonomous systems, all which may benefit NASA exploration or the development of new aerospace industry or products."

Thirty-five teams, from 18 states and Puerto Rico, launched their single-stage rockets during the 15th annual competition held near Marshall. To determine the winning teams, data from each of the flights were analyzed over the following weeks and the results of the analyses were combined with results from technical design reviews and other products required before launch day.

Four NASA Heroes Inducted into U.S. Astronaut Hall of Fame

NASA's Associate Administrator for the Science Mission Directorate John Grunsfeld and former astronauts Steve Lindsey, Kent Rominger, and M. Rhea Seddon were inducted into the U.S. Astronaut Hall of Fame on May 30, bringing the total number of Hall of Fame space explorers to 91. NASA Administrator Charles Bolden, a 2006 hall of famer, and 2008 inductee Bob Cabana, director of NASA's Kennedy Space Center in Florida, presided over the ceremony at Kennedy's visitor complex to welcome the new inductees. "To John Grunsfeld, Steve Lindsey, Kent Rominger, Rhea Seddon — I offer my deepest congratulations," said Bolden. "You have my deepest respect for all you have achieved in space, for the example you set for others, and the inspiration you have given future generations to take us on a journey to Mars."

Grunsfeld was selected as a NASA astronaut in March 1992. A five-flight veteran, he logged more than 58 days in space, including 58 hours and 30 minutes of extravehicular activity during eight spacewalks. Three of his missions focused on repairing and upgrading NASA's Hubble Space Telescope. He went on to serve as the deputy director of the Space Telescope Science Institute in Baltimore, managing the science programs for Hubble and the James Webb Space Telescope, scheduled for launch in October 2018. Grunsfeld was selected in January 2012 to his current position at NASA Headquarters in Washington.

NASA Associate Administrator for the Science Mission Directorate and astronaut John Grunsfeld (center) is inducted into the U.S. Astronaut Hall of Fame on May 30, 2015 at the NASA Kennedy Space Center Visitor Complex in Florida. Shaking Grunsfeld's hand is Dan Brandenstein, chair of the board of directors for the Astronaut Scholarship Foundation, and standing next to Grunsfeld is former NASA astronaut Steve Hawley. Credit: NASA.

Lindsey was selected for NASA's astronaut corps in March 1995. A veteran of five spaceflights, he logged more than 63 days in space. Lindsey served on several notable missions, including STS-95 alongside former astronaut and U.S. senator John Glenn; STS-121, the second Return to Flight mission after the loss of space shuttle Columbia; and STS-133, the final flight of space shuttle Discovery.

NASA selected Rominger to become an astronaut in 1992. Also a veteran of five spaceflights — three as pilot and two as commander — he logged more than 67 days in space. Several of Rominger's missions were integral to the beginnings of the International Space Station. As commander of the STS-96 mission, Rominger oversaw the first docking of a space shuttle to the station.

Seddon was selected by NASA in January 1978 to the first U.S. astronaut class to include women, and became an astronaut in August 1979. A three-flight veteran, she logged more than 30 days in space. In addition to participating in and leading numerous science and medical experiments during her flights, Seddon also helped develop and implement a variety of programs and plans for the shuttle program.

National Space Society Awards Physicist Kip Thorne Its Mass Media Space Pioneer Award

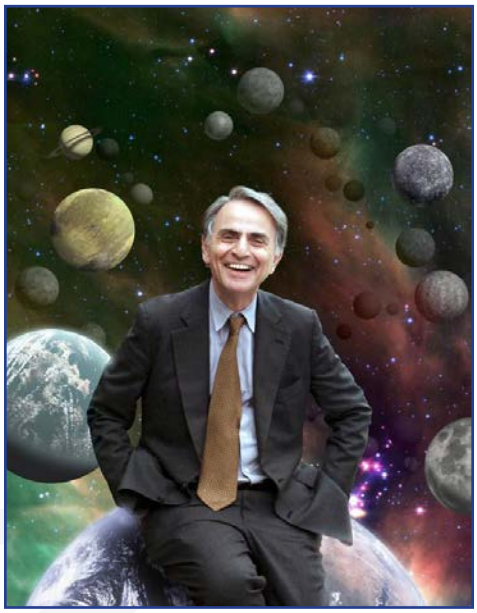
National Space Society

The National Space Society (NSS) has announced that physicist Dr. Kip Thorne is the recipient of its 2015 Space Pioneer Award for "Mass Media." The award was presented at the 2015 International Space Development Conference, which was held in May in Toronto, Canada.

Thorne was honored for his work on the movie *Interstellar* and his related 2014 book *The Science of Interstellar*. The visual effects in the movie have greatly improved our concepts of what a black hole might look like and the weird but real physical effects associated with it. Even though we are many decades away from being able to seriously start the technical design work for a practical interstellar vehicle, cinema productions like *Interstellar* keep the public aware of the vast cosmos with a literal plethora of planets waiting outside our world and the potential and challenge it presents to us.

Thorne has had a very long and distinguished career as a physicist, physics professor, and author. Physics is the bedrock of space science, and what he has taught is vital to professionals working in the space community. Thorne co-authored the landmark physics textbook *Gravitation*. He held the position of the Feynman Professor of Theoretical Physics at the California Institute of Technology from 1991 to 2009, when he left the position to work outside the university. His work in *Interstellar* is one of the results. Thorne is good friends with world-famous physicist Stephen Hawking, a prior recipient of the NSS's prestigious Heinlein Award.

NASA Selects 2015 Carl Sagan Fellows



The Sagan Fellowship program, named after the late Carl Sagan (shown here), supports talented young scientists in their mission to explore the unknown. Following the path laid out by Sagan, these bright fellows will continue to tread the path, make their own discoveries, and inspire future Sagan fellows. Credit: NASA/ Cosmos Studies.

NASA has selected six scientists as recipients of the 2015 Carl Sagan Exoplanet Postdoctoral Fellowships. The fellowship, named for the late astronomer, was created in 2008 to inspire the next generation of explorers seeking to learn more about planets, and possibly life, around other stars. The Sagan Fellowship's primary goal is to support outstanding recent postdoctoral scientists in conducting independent research related to the science goals of NASA's Exoplanet Exploration Program, namely, to discover and characterize planetary systems and Earth-like planets around nearby stars.

Significant discoveries and advances have already been made by previous Sagan Fellows. Recent science results from the fellows include the most precise measurement ever of the radius of a planet outside our solar system, and images of exoplanets obtained with an Earth-based telescope using the same type of imaging sensor found in digital cameras. "The Sagan Fellowships attract the best and brightest early career researchers in the rapidly developing field of exoplanets. They are pushing the boundaries of finding and characterizing the most Earth-like around the coolest, nearest stars," said Charles Beichman, executive director of the NASA Exoplanet Science Institute at the California Institute of Technology in Pasadena. "Their research will make advances in exoplanet theory and instrumentation, and take full advantage of NASA missions."

The 2015 Sagan Fellows are:

— Courtney Dressing, who will work at the California Institute of Technology in Pasadena on "Characterizing Small Planets Orbiting Small Stars." Dressing will use data from NASA's Kepler space telescope and its follow-on mission, K2, to distinguish false positive planet candidates and to characterize red dwarfs hosting small planets. She will also measure the mass of small planets to further characterize their compositional properties and investigate the link between stellar hosts and planetary properties.

— Daniel Foreman-Mackey, who will work at the University of Washington in Seattle on "Flexible and Robust Inference of the Exoplanet Population." Foreman-Mackey will use statistical methods to examine the large catalog of exoplanet discoveries, studying their distribution as a function of their physical parameters. He plans to derive a common framework for robust population inference and to apply this method to existing and forthcoming catalogs of exoplanet data.

— Jonathan Gagne, who will work at the Carnegie Institute for Science in Washington on "Locating the Young, Isolated Planetary-Mass Objects in the Solar Neighborhood." Gagne will use groundbased observations to explore the connection between the atmospheres of brown dwarfs and those of giant exoplanets. This will constrain the initial mass function down to a few times the mass of Jupiter, hence testing the recent prediction that the spatial density of isolated Jupiter-mass objects is twice as large as that of stars.

— Paul Robertson, who will work at Pennsylvania State University in State College on "Spotting Blue Planets Around Spotted Red Stars: Removing Stellar Activity from Radial Velocities of M Dwarf Stars." Robertson plans to develop a generalized method for disentangling stellar activity from radial velocity (RV) measurements of M stars in near-infrared wavelengths. He will develop a multi-dimensional modeling package that simultaneously models planet signals and activity-RV correlations, rather than separating analyses of the two. This will lead to robust detections of low-mass planets in the habitable zone.

— Ty Robinson, who will work at the University of California in Santa Cruz on "Bridging the Theory Gap: Developing a Novel Cloud Model for Exoplanets." Robinson is interested in understanding cloud dynamics, which are key to characterizing and modeling exoplanets. Clouds strongly influence many exoplanet observations, and Robinson will work toward developing new and efficient cloud models that lead to better interpretation of exoplanet observations.

— Leslie Rogers, who will work at the University of California in Berkeley on "Searching for Water in Distant Worlds." Rogers will use three approaches, atmospheric transmission spectra, exoplanet radio aurora emissions, and the accumulating statistical ensemble of planet mass-radius, to constrain the bulk water content of distant exoplanets. These data will be used to evaluate planet formation theories for the abundance of Neptune-sized exoplanets.

NASA has two other astrophysics theme-based fellowship programs: the Einstein Fellowship Program, which supports research into the physics of the cosmos, and the Hubble Fellowship Program, which supports research into cosmic origins. The Sagan Fellowship Program is administered by the NASA Exoplanet Science Institute as part of NASA's Exoplanet Exploration Program at the Jet Propulsion Laboratory in Pasadena, California.

Jurczyk Named Head of NASA Space Technology Mission Directorate

NASA Administrator Charles Bolden has named Steve Jurczyk as the agency's Associate Administrator for the Space Technology Mission Directorate, effective Monday, March 2. The directorate is responsible for innovating, developing, testing, and flying hardware for use on future NASA missions.

NASA's Steve Jurczyck addresses an audience during a manufacturing event in Hampton, Virginia, last month. Credit: NASA/Gary Banziger.

Jurczyk has served as Center Director at NASA's Langley Research Center in Hampton, Virginia, since April 2014. An accomplished engineer, he previously served as the deputy center director and in other leadership positions at the center prior to his appointment as center director. "It's great to have Steve coming onboard to lead the technology and innovation engine of the agency," said Bolden. "Technology drives exploration and under Steve's leadership we'll continue the President's innovation strategy, positioning NASA and the aerospace community on the cutting-edge, pushing the boundaries of the aerospace with the technical rigor our nation expects of its space program." Langley's current deputy director, Dave Bowles, will serve as acting director.

In May 2003, Jurczyk was named director of Systems Engineering. Before becoming Langley's Deputy Director, he previously served as director of Langley's Research and Technology Directorate. Jurczyk began his NASA career at Langley in 1988 as an electronics engineer in the Electronic Systems Branch. While on detail to NASA Headquarters, he managed the Tropical Rainfall Measuring Mission and formulated the technology development strategy for the Earth Science Enterprise.

From 1994 to 1997, he was the Instrument Systems Engineer and later the Spacecraft Systems Manager for the Landsat 7 Project at Goddard Space Flight Center in Greenbelt, Maryland. He returned to Langley as head of the Electronic Systems Branch in the Aerospace Electronics Systems Division. In 2002, Jurczyk was selected as Deputy Director for Flight Systems in Langley's Systems Engineering organization.

Jurczyk earned bachelor and master of science degrees in electrical engineering from the University of Virginia in 1984 and 1986, respectively. Jurczyk succeeds Michael Gazarik, who left this agency this month to become director of Technology at Ball and Technologies Corp. in Boulder, Colorado.

NASA Announces New Director of Ames Research Center

NASA Administrator Charles Bolden announced on May 4 the selection of Dr. Eugene L. Tu as the next director of the agency's Ames Research Center in Moffett Field, California, effective immediately. Tu most recently served as the director of Exploration Technology at Ames, where he led four technology research and development divisions, including two of NASA's critical infrastructure assets: the consolidated arc jet testing complex and the agency's primary supercomputing facility.

Tu's career in aeronautics began as a research scientist, conducting computational fluid dynamics research on the aerodynamics of complex aircraft configurations. He has held research and managerial positions at the center in computational aerodynamics, information technology, and high performance computing and communications. He also served in the Office of Biological and Physical Research at NASA Headquarters in Washington.

Dr. Eugene L. Tu. Credit: NASA.

Tu has a Bachelor's degree in mechanical engineering from the University of California, Berkeley, and a master's and doctorate in aeronautics and astronautics from Stanford University. He is an associate fellow of the American Institute of Aeronautics and Astronautics (AIAA) and received the NASA Outstanding Leadership Medal in 2000 and Presidential Rank Award for Meritorious Executive in 2009.

Dava Newman Begins Work as NASA's Deputy Administrator

NASA Deputy Administrator Dr. Dava Newman walks to a meeting with NASA Administrator Charles Bolden, on Monday, May 18, her first day on the job at NASA Headquarters in Washington. Credit: NASA/Bill Ingalls.

Dava Newman started her official duties as NASA's new deputy administrator on May 18 at the agency's headquarters in Washington. Newman was nominated in January by President Obama, confirmed by the Senate in April, and sworn in on Friday, May 15. The deputy administrator position had been vacant since the departure of Lori Garver in September 2013.

Newman is responsible to the agency administrator for providing overall leadership, planning, and policy direction for NASA. Newman will perform the duties and exercises the powers delegated by the administrator, assists the administrator in making final agency decisions, and acts for the administrator in his absence by performing all necessary functions to govern NASA operations and exercises the powers vested in the agency by law. Newman also is responsible for articulating the agency's vision and representing NASA to the Executive Office of the President, Congress, heads of federal and other appropriate government agencies, international organizations, and external organizations and communities.

"I'm very excited to be at NASA," said Newman. "I'm looking forward to being a part of the agency's work to expand humanity's reach into space, advance our journey to Mars, and strengthen America's leadership here at home."

Prior to her tenure with NASA, Newman was the Apollo Program Professor of Astronautics at the Massachusetts Institute of Technology (MIT) in Cambridge. Her expertise is in multidisciplinary research that encompasses aerospace biomedical engineering. Newman's research studies were carried out through space flight experiments, groundbased simulations, and mathematical modeling. Her latest research efforts included advanced space suit design, dynamics and control of astronaut motion, mission analysis, and engineering systems design and policy analysis. She also had ongoing efforts in assistive technologies to augment human locomotion here on Earth.

Newman is the author of *Interactive Aerospace Engineering and Design,* an introductory engineering textbook published by McGraw-Hill, Inc., in 2002. She also has published more than 250 papers in journals and conference volumes.

As a student at MIT, Newman earned her Ph.D. in aerospace biomedical engineering in 1992 and Master of Science degrees in aerospace engineering and technology and policy in 1989. She earned her Bachelor of Science degree in aerospace engineering from the University of Notre Dame in 1986.

Nathaniel Comfort Named to Chair in Astrobiology at John W. Kluge Center

Librarian of Congress James H. Billington has named Nathaniel Comfort to hold the third Baruch S. Blumberg NASA/Library of Congress Chair in Astrobiology in the John W. Kluge Center at the Library of Congress. He will begin on October 1, 2015, and be in residence for 12 months.

Dr. Nathaniel Comfort. Credit: Johns Hopkins University.

A well-known historian of recent science (science of the recent past), biology, and biomedicine, Comfort is currently a professor at the Institute of the History of Medicine at The Johns Hopkins University. His books include *The Science of Human Perfection: How Genes Became the Heart of American Medicine* (2012) and *The Tangled Field: Barbara McClintock's Search for the Patterns of Genetic Control* (2001).

While at the Library, Comfort will use the collections to examine the history of the genomic revolution in origin-of-life research. He said, "Genomics represents not just a new approach to genetics, but a new style of thought. It is transforming all the life sciences, from medicine to ecology, to evolution, to astrobiology."

Comfort's research addresses one of the central areas of inquiry in the field of astrobiology, which, in addition to the search for life elsewhere in the universe, is deeply interested in how life began and evolved here on Earth. Comfort will make use of the Library's extensive manuscript collections of notable scientists, including the Carl Sagan archive and the Barry Commoner, Maxine Singer, and George Gamow papers, as well as the resources in the Library's Science, Technology, and Business Division and the Library's general collections.

The Astrobiology Chair at the Kluge Center is the result of collaboration between the NASA Astrobiology Program and the Library of Congress. It is named for Baruch "Barry" Blumberg, the late Kluge Center Scholars Council member, Nobel laureate, and founding director of the NASA Astrobiology Institute.

Funded by NASA, and executed by the Kluge Center in consultation with the NASA Astrobiology Institute, the chair holder conducts research at the intersection of the science of astrobiology and its humanistic and societal implications. One senior researcher is appointed annually to be in residence at the John W. Kluge Center, to make use of the Library of Congress collections in exploration of these questions, as well as to convene related programs on astrobiology's role in culture and society. Comfort becomes the third distinguished scholar to hold the Astrobiology Chair; previous chair holders include renowned astrobiologist and planetary scientist David Grinspoon (2012–2013) and Steven Dick, former chief historian at the National Aeronautics and Space Administration (2013–2014).

National Science Board selects American Museum of Natural History for 2015 Public Service Award

On April 22 the National Science Board (NSB) announced that it had selected New York City's American Museum of Natural History (AMNH) for its 2015 Public Service Award. This prestigious award honors exemplary public service in promoting public understanding of science and engineering.

"Each year, the American Museum of Natural History shares the excitement and wonder of science with millions of students, teachers, families, and other members of the public with its exhibitions and public programs," said Vint Cerf, Chair of NSB's Committee on Honorary Awards. "Additional initiatives of the museum contribute to the teaching and learning of science and the training of the next generation of scientists."

Founded in 1869, AMNH's mission is to "discover, interpret, and disseminate — through scientific research and education — knowledge about human cultures, the natural world, and the universe." The museum's scientific assets feature more than 33 million specimens and artifacts, 200 scientific staff, and interdisciplinary research in areas that include genomics, computational biology, and astrophysics. In recent years, the museum has leveraged its education and science resources to address science education needs and help develop future scientists. These initiatives include partnerships with urban schools, a Master of Arts in Teaching program with a focus on Earth science, a museum-based doctoral program in comparative biology, and a mentoring program to provide research and laboratory experiences for underresourced high school students.

"We are honored to receive this award from the National Science Board in recognition of the Museum's efforts to address the national crisis in science education, to increase the public understanding of science, and to prepare the next generation of scientists, science teachers, and scientifically literate citizens," said Ellen V. Futter, President of AMNH. "We live in a time when many of our most pressing problems and opportunities are science based, a time in which scientific advancement and science literacy are essential elements in our nation's continued leadership and key to a shared global future that is sustainable, responsible, and peaceful. Museums like the American Museum of Natural History have an important role to play in this, and we are honored to be recognized by the National Science Board."

NSB presented AMNH with the Public Service Award on May 5, 2015, during its annual awards ceremony in Washington, DC. Past recipients of NSB's Public Service Award — established in the late

1990s — include The Alfred P. Sloan Foundation, PBS television series NOVA, and The Expanding Your Horizons Network.

NASA Wins 2015 Webby Awards

Three websites and a mobile app from NASA are among the winners of the 2015 Webby Awards, which were announced on April 27 in New York. NASA's Jet Propulsion Laboratory was a Webby award winner and People's Voice award winner in the "Websites: Government" category; NASA's Global Climate Change was a Webby award winner and People's Voice award winner in the "Websites: Green" category; and NASA GeneLab was a Webby award winner in the "Websites: Best Navigation" category.

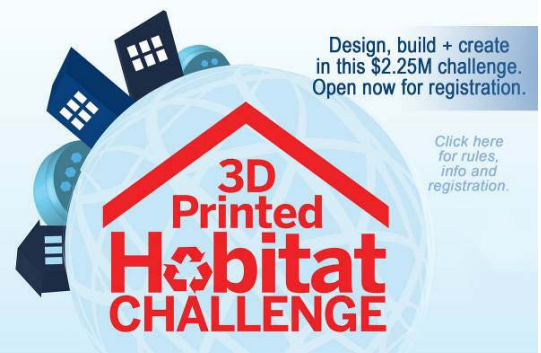
In addition, NASA's Earth Now mobile app was a Webby award winner in the "Mobile Sites & Apps: Education and Reference" category.

Previously, the Global Climate Change website won the juried Webby award in the "Websites: Science" category in 2011, the People's Voice Webby award for best science site in 2010, and was an official honoree in the science site category in 2009.

For this year, The Webby Awards received nearly 13,000 entries from all 50 U.S. states and more than 60 countries worldwide. Approximately 1000 nominees were selected from the entries and placed into dozens of categories for voting. A full list of winners is available at *http://www.webbyawards.com/winners*.

NASA Challenges Designers to Construct Habitat for Deep Space Exploration

NASA and the National Additive Manufacturing Innovation Institute, known as America Makes, are holding a new $2.25 million competition to design and build a 3-D printed habitat for deep space exploration, including the agency's journey to Mars. The multi-phase 3-D Printed Habitat Challenge, part of NASA's Centennial Challenges program, is designed to advance the additive construction technology needed to create sustainable housing solutions for Earth and beyond.



Shelter is among the most basic and crucial human needs, but packing enough materials and equipment to build a habitat on a distant planet would take up valuable cargo space that could be used for other life-sustaining provisions. The ability to manufacture a habitat using indigenous materials, combined with material that would otherwise be waste from the spacecraft, would be invaluable.

The first phase of the competition, announced on May 16 at the Bay Area Maker Faire in San Mateo, California, runs through September 27. This phase, a design competition, calls on participants to develop

state-of-the-art architectural concepts that take advantage of the unique capabilities 3-D printing offers. The top 30 submissions will be judged and a prize purse of $50,000 will be awarded at the 2015 World Maker Faire in New York.

"The future possibilities for 3-D printing are inspiring, and the technology is extremely important to deep space exploration," said Sam Ortega, Centennial Challenges program manager. "This challenge definitely raises the bar from what we are currently capable of, and we are excited to see what the maker community does with it."

The second phase of the competition is divided into two levels. The Structural Member Competition (Level 1) focuses on the fabrication technologies needed to manufacture structural components from a combination of indigenous materials and recyclables, or indigenous materials alone. The On-Site Habitat Competition (Level 2) challenges competitors to fabricate full-scale habitats using indigenous materials or indigenous materials combined with recyclables. Both levels open for registration September 26, and each carries a $1.1 million prize.

Winning concepts and products will help NASA build the technical expertise to send habitat-manufacturing machines to distant destinations, such as Mars, to build shelters for the human explorers who follow. On Earth, these capabilities may be used one day to construct affordable housing in remote locations with limited access to conventional building materials.

For more information about the 3-D-Printed Habitat Challenge, visit *http://AmericaMakes.us/Challenge* or *http://www.nasa.gov/3DPHab*.

NASA Selects Advanced Space Technology Concepts for More Study

NASA has selected 15 proposals, including one from the Jet Propulsion Laboratory (JPL), for study under Phase I of the NASA Innovative Advanced Concepts (NIAC), a program that aims to turn science fiction into science fact through the development of pioneering technologies. The chosen proposals cover a wide range of inventive concepts, selected for their potential to transform future aerospace missions. Such transformational technology holds promise of accelerating NASA's progress toward its goals of exploration beyond low-Earth orbit, and missions to an asteroid and Mars.

"The latest NIAC selections include a number of exciting concepts," said Steve Jurczyk, associate administrator for the Space Technology Mission Directorate (STMD) at NASA Headquarters in Washington. "We are working with American innovators to reimagine the future of aerospace and focus our investments on concepts to address challenges of current interests both in space and here on Earth."

NIAC Phase I awards are valued at approximately $100,000, providing awardees the funding needed to conduct a nine-month initial definition and analysis study of their concepts. If the basic feasibility studies are successful, awardees can apply for Phase II awards, valued up to $500,000 for two additional years of concept development.

"Most of the 2015 NIAC Phase I final candidates were outstanding, and choosing only 15 of them proved to be a challenge," said Jason Derleth, NIAC program executive. "We look forward to seeing how each new study will push boundaries and explore new approaches — that's what makes NIAC unique."

The objective of the JPL proposal is to develop new mission concepts for *in situ* observational atmospheric science on Jupiter and Saturn with persistent high-mobility WindBots, harvesting energy from the strong winds and magnetic fields, and to evaluate the feasibility of WindBots. The study will open new avenues for *in situ* atmospheric science missions on gas giants, with high-mobility explorers, which would lead to dramatically better understanding of gas giants; will establish a basis for systematic incorporation of energy-harvesting techniques in the design of planetary robots; and will lead to new concepts of persistent exploration and sensor networks made of smaller/cheaper robots without the nuclear energy overhead.

Another selected proposal calls for the use of a soft-robotic rover for missions that can't be accomplished with conventional power systems. This rover would resemble an eel with a short antenna on its back that harvests power from locally changing magnetic fields. The goal is to enable amphibious exploration of gas-giant moons like Europa.

One of the proposals will look at using two glider-like unmanned aerial vehicles connected by an ultra-strong cable at different altitudes that sail without propulsion. The vehicle would use wind shear in the lower stratosphere (approximately 18,288 meters, or 60,000 feet), similar to a kite surfer, where the upper aircraft provides lift and aerodynamic thrust, and the lower aircraft provides an upwind force to keep it from drifting downwind. If successful, this atmospheric satellite could remain in the stratosphere for years, enabling NASA's Earth science missions, monitoring capabilities or aircraft navigation at a fraction of the cost of orbital satellite networks.

Employing a novel mobility concept, the Cryogenic Reservoir Inventory by Cost-Effective Kinetically Enhanced Technology (CRICKET) proposal explores volatiles, such as hydrogen, nitrogen, and water, stored in permanently shadowed regions on planetary bodies. Inexpensive robotic crawlers, hoppers, and soccer-ball style buckey-bots would explore the surface of these dark regions for water and other compounds. Multiple bots could be used to develop a high-resolution map to aid in potentially using these resources.

NASA solicits visionary, long-term concepts for technological development based on their potential value to future and current space missions. The projects are chosen through a peer-review process that evaluates their potential, technical approach, and benefits that can be realized in a reasonable timeframe. All concepts are very early in the development cycle and represent multiple technology areas, including aircraft propulsion, human life support, science instruments, unique robotic concepts, and exploring other diverse technology paths needed to meet NASA's strategic goals. NASA's early investments and partnerships with forward-thinking scientists, engineers, and citizen inventors from across the nation will provide technological dividends and help maintain America's leadership in the global technology economy.

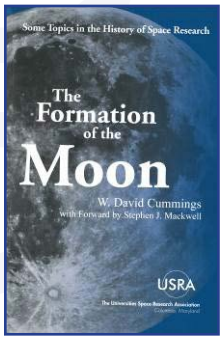
NIAC is part of NASA's Space Technology Mission Directorate, which innovates, develops, tests, and flies hardware for use in NASA's future missions. During the next 18 months, the directorate will make significant new investments to address several high-priority challenges in achieving safe and affordable deep space exploration.

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

BOOKS

The Formation of the Moon.

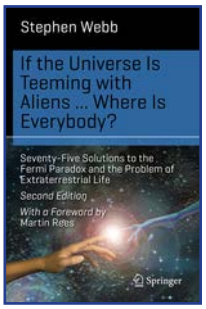
By W. David Cummings. Universities Space Research Association. 2015, 370 pp., Paperback. Available free of charge through December 2015 (or while supplies last) by contacting the author directly at *wcummings@usra.edu*



This book chronicles major questions pertaining to the processes that formed the major features on the lunar nearside and how understanding evolved as better observations were obtained, and ultimately as lunar samples provided ground truth. The book also describes the role of the Lunar Science Institute (now the Lunar and Planetary Institute) in drawing the lunar science community together for conferences and workshops to discuss the latest results and models for the formation and evolution of the Moon and the Earth-Moon system. The book details the key points of discussion and how they evolved through these LSI/LPI-sponsored meetings, leading to the understanding of the Moon at the time of the "Origin of the Moon" conference in Kona, Hawaii, in October 1984. Although this book focuses on the evolution in knowledge of the Moon during a period of rapid change in our ability to measure its structure and properties, it provides an additional perspective on how science evolves as technology advances and enables major new insight into the physical universe. While such paradigm-shifting events have occurred throughout history, rarely have we been provided with such a clear demonstration of how new data infuse the scientific establishment, are debated, and ultimately generate fundamental new understanding.

If the Universe Is Teeming with Aliens . . . Where Is Everybody?, second edition.

By Stephen Webb. Springer. 2015, 434 pp., Paperback, $29.99. *www.springer.com*

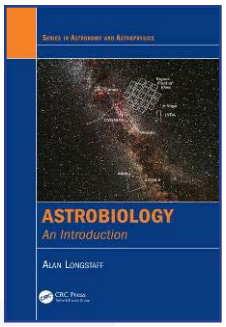


Given the fact that there are perhaps 400 billion stars in our galaxy alone, and perhaps 400 billion galaxies in the universe, it stands to reason that somewhere out there, in the 14-billion-year-old cosmos, there is or once was a civilization at least as advanced as our own. The sheer enormity of the numbers almost demands that we accept the truth of this hypothesis. Why, then, have we encountered no evidence, no messages, no artifacts of these extraterrestrials? In this second, significantly revised and expanded edition of his widely popular book, author Webb discusses in detail the (for now) 75 most cogent and intriguing solutions to Fermi's famous paradox: If the numbers strongly point to the existence of extraterrestrial civilizations, why have we found no evidence of them?

Astrobiology: An Introduction.

By Alan Longstaff. CRC Press, 2014, Hardcover, 466 pp., $89.95. *www.crcpress.com*

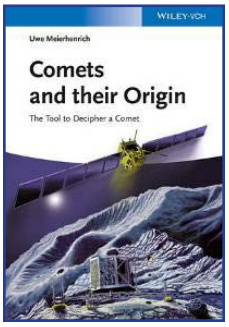
Astrobiology is a multidisciplinary pursuit that in various guises encompasses astronomy, chemistry, planetary and Earth sciences, and biology. It relies on mathematical, statistical, and computer modeling for theory, and space science, engineering, and computing to implement observational and experimental work. Reflecting this multi-science approach, this book covers topics such as stellar evolution, cosmic



chemistry, planet formation, habitable zones, terrestrial biochemistry, and exoplanetary systems; discusses the origin, evolution, distribution, and future of life in the universe in an accessible manner, sparing calculus, curly arrow chemistry, and modeling details; and contains problems and worked examples, including a solutions manual with qualifying course adoption. *Astrobiology: An Introduction* provides a full introduction to astrobiology suitable for university students at all levels.

Comets and Their Origin: The Tools to Decipher a Comet.

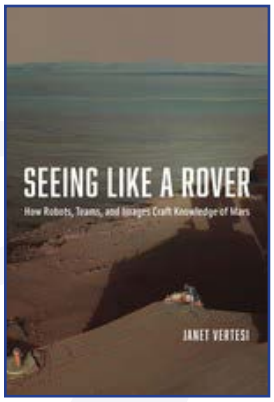
By Uwe Meierhenrich. Wiley, 2015, 352 pp., Hardcover, $175.00. *www.wiley.com*



Divided into two parts, the first four chapters of this book refer to comets and their formation in general, describing cometary missions, comet remote observations, astrochemistry, artificial comets, and the chirality phenomenon. The second part covers the cometary Rosetta mission, its launch, journey, scientific objectives, and instrumentations, as well as the landing scenario on a cometary nucleus. Along the way, the author presents general questions concerning the origin of terrestrial water and the molecular beginnings of life on Earth, as well as how the instruments used on a space mission like Rosetta can help answer them. The text concludes with a chapter on what scientists expect from the Rosetta mission and how its data will influence our life on Earth. As a result, the author elucidates highly topical and fascinating knowledge to scientists and students of various scientific backgrounds.

Seeing Like a Rover: How Robots, Teams, and Images Craft Knowledge of Mars.

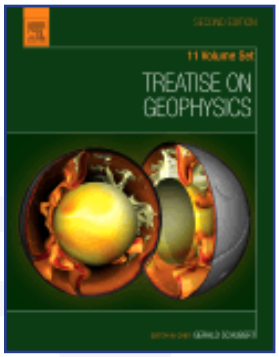
By Janet Vertesi. University of Chicago Press, 2015, 304 pp., Hardcover, $31.50. *www.press.uchicago.edu*



In the years since the Mars Exploration Rovers Spirit and Opportunity first began transmitting images from the surface of Mars, we have become familiar with the harsh, rocky, rusty-red martian landscape. But those images are much less straightforward than they may seem to a layperson: Each one is the result of a complicated set of decisions and processes involving a large team behind the rovers. With *Seeing Like a Rover*, author Vertesi takes us behind the scenes to reveal the work that goes into creating our knowledge of Mars. Every photograph that the rovers take must be processed, manipulated, and interpreted — and all of that comes *after* the team members negotiate with each other about what they should even be taking photographs of in the first place. Vertesi's account of the inspiringly successful rover project reveals science in action, a world where digital processing uncovers scientific truths, where images are used to craft consensus, and where team members develop an uncanny intimacy with the sensory apparatus of a robot that is millions of miles away. Ultimately, every image taken by the Mars rovers is not merely a picture of Mars — it's a portrait of the whole rover team as well.

Treatise on Geophysics, second edition.

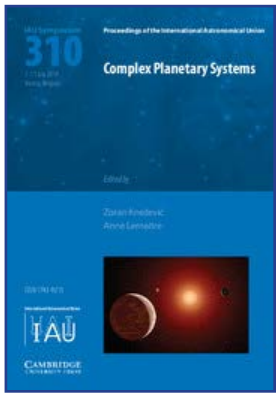
Edited by Gerald Schubert. Elsevier, 2015, 5604 pp. in 11 volumes, Hardcover, $4200.00. *www.elsevier.com*



Treatise on Geophysics, second edition, is a comprehensive and in-depth study of the physics of Earth beyond what any geophysics text has provided previously. Thoroughly revised and updated, it provides fundamental and state-of-the-art discussion of all aspects of geophysics. A highlight of the second edition is a new volume on "Near Surface Geophysics" that discusses the role of geophysics in the exploitation and conservation of natural resources and the assessment of degradation of natural systems by pollution. Additional features include new material in the "Planets and Moon," "Mantle Dynamics," "Core Dynamics," "Crustal and Lithosphere Dynamics," "Evolution of the Earth," and "Geodesy" volumes. New material is also presented on the uses of Earth gravity measurements. This title is essential for professionals, researchers, professors, and advanced undergraduate and graduate students in the fields of geophysics and Earth system science.

Complex Planetary Systems (IAU Symposium 310).

Edited by Zoran Knežević and Anne Lemaître. Cambridge University Press, 2015, 250 pp., Hardcover, $125.00. *www.cambridge.org*



Complex Planetary Systems takes a broad look at the complexity of planetary systems, in terms of the formation and dynamical evolution of planets, their satellites, minor bodies and space debris, as well as the habitability of exoplanets, in order to understand and model their physical processes. The main topics covered are diverse, including studies of the rotation of planets and satellites, including their internal structures; the long-term evolution of space debris and satellites; planetary and satellite migration mechanisms; and the role of the Yarkovsky effect on the evolution of the rotating small bodies. Intended for researchers and advanced students studying complex planetary systems, this book will appeal to nonspecialists interested in problems such as the habitability of exoplanets, planetary migration in the early solar system, or the determination of chaotic orbits. This volume provides a valuable insight into the state-of-the-art research in this exciting interdisciplinary field.

DVDs

NASA Collection.

Produced by Topics Entertainment, 2015, 10 disks. $39.99. *www.topics-ent.com*

The *NASA Collection* is a 10-DVD set covering America's history of space exploration, with special introductions by astronauts including Alan Shepard, Wally Schirra, Rusty Schweickart, Rick Hauck, Bob Overmyer, Walt Cunningham, Pete Conrad, and Charlie Duke. This special collection covers everything from the original story of America's first manned space flight, to Moon walking, the Apollo/Soyuz mission, zero-gravity experiments, the space shuttle, and more. Bonus programs "Who's Out There?" (1975), hosted by Orson Welles, and "The Universe" (1976), narrated by William Shatner, are included.

FOR KIDS!!!

TIME for Kids The BIG Book of Why: Stellar Space.

By the Editors of Time for Kids Magazine. Capstone Press, 2015, 48 pp., Hardcover. $26.65. *www.capstonepub.com*

TIME for Kids The BIG Book of Why: Stellar Space answers the why, what, when, where, who, and how questions about Earth and space that kids commonly ask, but adults can rarely answer. Why don't we fall off the planet? Why is the sky blue? Why are diamonds so rare? Why is the Sun so bright? Where does our solar system end? Written in an upbeat manner, each answer is accompanied by either a photo or an illustration to show the reasons why. Of course, *TIME for Kids* goes beyond answering the question, and dips into the science or history to further explain the answer in an easy-to-follow, straightforward manner. *TIME for Kids The BIG Book of Why: Stellar Space* is a must-have book to satisfy the most curious of kids. For grades 5 to 6.

Star Stuff: Carl Sagan and the Mysteries of the Cosmos.

By Stephanie Roth Sisson. Roaring Brook Press, 2014, 40 pp., Hardcover. $17.99. *us.macmillan.com/publishers/roaring-brook-press*

For every child who has ever looked up at the stars and asked, "What are they?" comes the story of a curious boy who never stopped wondering: Carl Sagan. When Sagan was a young boy he went to the 1939 World's Fair, and his life was changed forever. From that day on he never stopped marveling at the universe and seeking to understand it better. *Star Stuff* follows Sagan from his days stargazing from the bedroom window of his Brooklyn apartment, through his love of speculative science fiction novels, to his work as an internationally renowned scientist who worked on the Voyager missions exploring the farthest reaches of space. This book introduces the beloved man who brought the mystery of the cosmos into homes across America to a new generation of dreamers and star gazers. For ages 4 to 8.

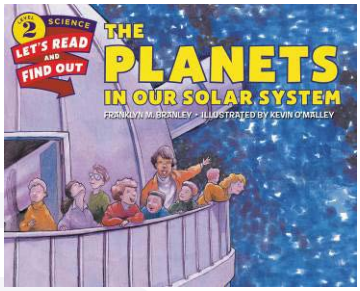
Giant Mars Volcano Project Kit.

Produced by Thames and Kosmos. $19.99. *www.thamesandkosmos.com*

Erupt a model of the largest volcano in our solar system, Olympus Mons on Mars. It is three times taller than Mt. Everest. Using a special plaster mixture and iron oxide powder, your mega-volcano hardens after each eruption and slowly grows like a real volcano. For ages 8 and up.

The Planets in Our Solar System.

By Franklyn M. Branley. Harper Collins, 2015, 32 pp., Paperback, $6.99. *www.harpercollins.com*



Where is it partly cloudy and 860°F? Venus! This classic picture book is a fascinating exploration of space written by children's nonfiction veteran and former chairman of the American Museum of Natural History's Hayden Planetarium, Franklyn M. Branley, and illustrated by Kevin O'Malley. Full of interesting facts about the eight planets in our solar system, including our very own Earth, this bestselling book also features photographs from Voyager and other space explorers. Reissued and now rebranded with a new cover, this book features a "Find Out More" section with instructions for making your own solar system mobile and web research prompts about how to track the Moon. Both text and artwork were vetted for accuracy by Jurrie van der Woude of NASA. For ages 4 to 8.

Calendar 2015

June

28–Jul 3 **Gordon Research Conference on Origins of Solar Systems,** South Hadley, Massachusetts. *http://www.grc.org/programs.aspx?id=12345*

29–Jul 1 **13th Meeting of the NASA Small Bodies Assessment Group (SBAG),** Washington, DC. *http://www.lpi.usra.edu/sbag/*

29–Jul 3 **From Super-Earths to Brown Dwarfs: Who's Who?,** Paris, France. *http://www.iap.fr/activites/colloques_ateliers/colloque_IAP/colloqueiap.php?annee=2015*

29–Jul 3 **Early E-ELT Science: Spectroscopy With HARMONI,** Oxford, UK. *http://harmoni2015.physics.ox.ac.uk*

July

1–13 **Nordic-Hawai'i Summer School "Water, Ice and the Origin of Life in the Universe,"** Reykjavik, Iceland. *http://www.nordicastrobiology.net/Iceland2015/*

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

6–8 **The Second Workshop on Measuring Precise Radial Velocities,** New Haven, Connecticut. *http://exoplanets.astro.yale.edu/workshop/EPRV/Home.html*

20 **Lunar and Small Bodies Graduate Conference 2015,** Mountain View, California. *http://impact.colorado.edu/lungradcon/2015/*

19–23 **2nd International Congress on Stratigraphy,** Graz, Austria. *http://strati2015.uni-graz.at/*

19–25 **Planetary Systems: A Synergistic View,** Quy Nhon, Vietnam. *http://rencontresduvietnam.org/conferences/2015/planetary-systems/*

21–23 **NASA Exploration Science Forum,** Moffett Field, California. *http://sservi.nasa.gov/ESF2015*

25–26 **The First Billion Years of Impact Records: Evidence from Lunar Samples and Meteorites,** Berkeley, California. *http://metsoc2015.ssl.berkeley.edu/program/workshops/*

27–31 **78th Annual Meteoritical Society Meeting,** Berkeley, California. *http://metsoc2015.ssl.berkeley.edu/*

August

2–7 **12th Annual Meeting of the Asia Oceania Geosciences Society (AOGS),** Singapore. *http://www.asiaoceania.org/aogs2015/*

3–7 **NBIA Summer School on Protoplanetary Disks and Planet Formation,** Copenhagen, Denmark. *http://www.nbia.dk/phd-school-2015*

3–14 **XXIX IAU General Assembly,** Honolulu, Hawaii. *http://astronomy2015.org*

4–6 **Second Landing Site Workshop for the Mars 2020 Rover,** Pasadena, California. *http://marsnext.jpl.nasa.gov*

12–14 **6th Planetary Crater Consortium Meeting,** Flagstaff, Arizona. *http://www.planetarycraterconsortium.nau.edu/*

17–21 **Cosmic Dust,** Tokyo, Japan. *https://www.cps-jp.org/~dust/Welcome.html*

18–20 **Planet Signatures from Precision Spectroscopy,** Sao Paulo, Brazil. *http://precisionspectroscopy.yolasite.com/*

21–22 **Cartography Beyond the Ordinary World,** Niteroi, Brazil. *http://niteroi2015.elte.hu*

24–26 **NASA Outer Planets Assessment Group Meeting,** Laurel, Maryland. *http://www.lpi.usra.edu/opag/*

24–27 **24th Annual Meeting on Characterization and Radiometric Calibration for Remote Sensing,** Logan, Utah. *http://www.calcon.sdl.usu.edu*

September

8–11 **Comparative Climates of Terrestrial Planets II: Understanding How Climate Systems Work,** Moffett Field, California. *http://cctp2.arc.nasa.gov/*

11–18 **IRAM 30m Summerschool 2015,** Pradollano, Spain. *http://www.iram-institute.org/EN/content-page-308-7-67-308-0-0.html*

15–17 **Life in a Cosmic Context,** Trieste, Italy. *https://www.ict.inaf.it/indico/event/106/*

21–25 **Radiation Mechanisms of Astrophysical Objects — Classics Today,** St. Petersburg, Russia. *http://www.astro.spbu.ru/sobolev100/?q=en/node/17*

21–26 **Bridging the Gap III: Impact Cratering in Nature, Experiments, and Modeling,** Freiburg, Germany. *http://www.hou.usra.edu/meetings/gap2015/*

27–Oct 2 **European Planetary Science Congress,** Nantes, France. *http://meetings.copernicus.org/epsc2015/*

October

5–8 **From Clouds to Protoplanetary Disks: The Astrochemical Link,** Berlin, Germany. *https://cas-events.mpe.mpg.de/indico/event/0/*

5–9 **Rainbows on the Southern Sky: Science and Legacy Value of the ESO Public Surveys and Large Programmes,** Garching, Germany. *http://www.eso.org/sci/meetings/2015/Rainbows2015.html*

9–15 **OHP 2015: Twenty Years of Giant Exoplanets,** Saint-Michel-l'Observatoire, France. *http://ohp2015.sciencesconf.org*

12–16 **Exploring the Universe with JSWT,** Noordwijk, The Netherlands. *http://congrexprojects.com/2015-events/15a02/introduction*

12–16 **Exoplanetary Atmospheres and Habitability,** Nice, France. *http://exoatmo.sciencesconf.org*

12–16 **66th International Astronautical Congress (IAC 2015),** Jerusalem, Israel. *http://iac2015.org/*

20–22 **Annual Meeting of the Lunar Exploration Analysis Group,** Columbia, Maryland. *http://www.hou.usra.edu/meetings/leag2015/*

20–23 **Second International Planetary Caves Conference,** Flagstaff, Arizona. *http://www.hou.usra.edu/meetings/2ndcaves2015/*

26–Nov 6 **COSPAR Capacity Building Workshop on Planetary Data Mission Analysis,** Guaratingueta, Brazil. *http://cbw.cosparbrazil2015.org/*

27–29 **13th Meeting of the Venus Exploration Analysis Group (VEXAG),** Washington, DC area. *http://www.lpi.usra.edu/vexag/*

28–29 **Missions to Habitable Worlds,** Budapest, Hungary. *http://life-origins2015.csfk.mta.hu/*

November

1–4 **Geological Society of America Annual Meeting,** Baltimore, Maryland. *http://community.geosociety.org/gsa2015/home*

2–4 **Workshop on Space Weathering of Airless Bodies,** Houston, Texas. *http://www.hou.usra.edu/meetings/airlessbodies2015/*

2–5 **K2 Science Conference (K2SCICON),** Santa Barbara, California. *http://lcogt.net/k2scicon/*

8–13 **47th Annual DPS Meeting,** National Harbor, Maryland. *http://dps.aas.org/*

9–13 **2nd Symposium of the Committee on Space Research (COSPAR): Water and Life in the Universe (COSPAR 2015),** Foz do Iguacu, Brazil. *http://cosparbrazil2015.org/*

11–13 **Joint Meeting of the Paneth Kolloquium and DFG SPP 1385 "The First 10 Million Years of the Solar System,"** Nördlingen, Germany. *http://www.paneth.eu/PanethKolloquium/Home.html*

16–20 **International Young Astronomers School on Large Ground-Based 21st Century Radio Instruments: ALMA/NOEMA-SKA/LOFAR/NenuFAR,** Paris, France. *http://ecole-doctorale.obspm.fr/-International-Young-Astronomers-School*

29–Dec 4 **Extreme Solar Systems III,** Waikoloa Beach, Hawaii. *http://ciera.northwestern.edu/Hawaii2015.php*

December

14–18 **AGU Fall Meeting,** San Francisco, California. *http://fallmeeting.agu.org/2015/*

January 2016

4–8 **American Astronomical Society 227th Meeting,** Kissimmee, Florida. *http://aas.org/meetings/aas227*

27–29 **14th Meeting of the NASA Small Bodies Assessment Group (SBAG),** Pasadena, California. *http://www.lpi.usra.edu/sbag/*