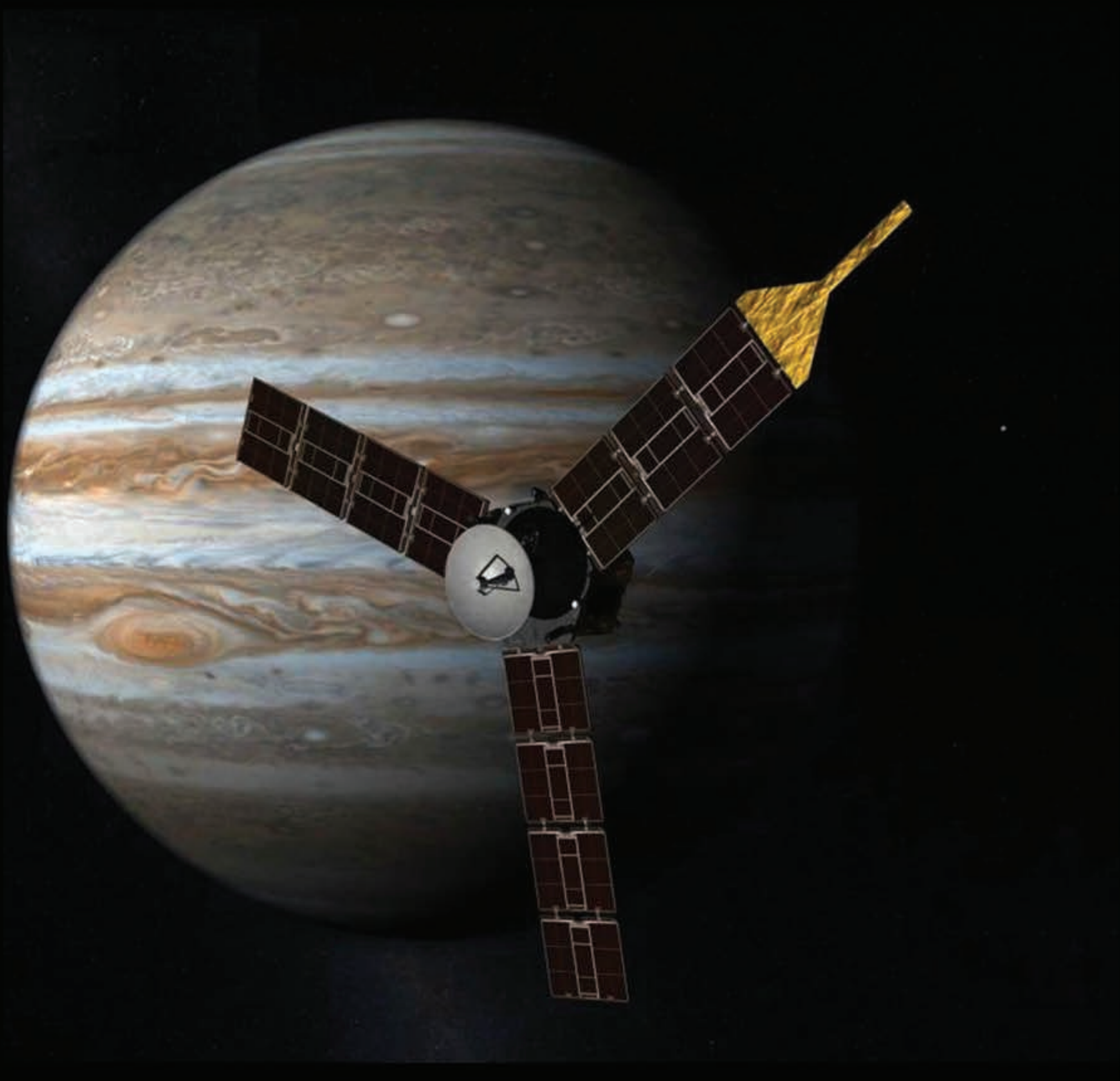
NASA's Juno Mission:
WHAT'S INSIDE JUPITER?



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— *Fran Bagenal, University of Colorado, Boulder*

Note from the editors — On July 4 of this year, the Juno spacecraft will become only the second manmade object to orbit the giant planet Jupiter, and the first since Galileo finished its Jupiter tour in 2003. In this article, Juno co-investigator Fran Bagenal previews the key science objectives of this "cloud-breaking" mission.

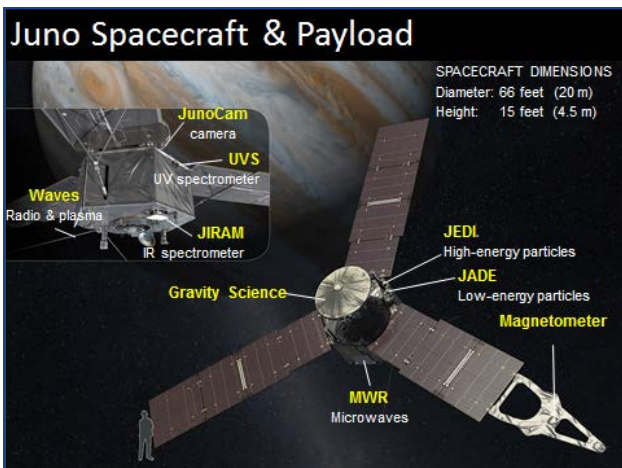
Jupiter is the king of planets in our solar system: It is the largest, has the most mass, the fastest spin, the strongest magnetic field, and the greatest number of satellites (67), of which its moon Europa is probably the most likely place on which to find extraterrestrial life. Moreover, we now know of hundreds of Jupiter-type planets that orbit other stars. Studies of the jovian system have ramifications that extend well beyond our solar system.

The swirling clouds on the exterior of Jupiter get all the public attention. But some of the keenest, cutting-edge issues of planetary science are hiding inside the planet. Does Jupiter have a core? How does the material flowing around inside generate such a strong magnetic field? And — perhaps the most important question for solar system formation — how much water is there inside Jupiter?

On December 7, 1995, a 750-pound (340-kilogram), 4.3-foot-diameter (1.3-meter) probe hurtled into Jupiter's atmosphere. Slowed by parachutes, and protected by a heat shield, the 7 scientific instruments on the Galileo probe measured the properties of the atmosphere for a little under an hour as it descended nearly 100 miles (161 kilometers) to pressures of over 23 atmospheres. The temperatures, pressures, and winds were not radically different from expectations, but the big surprise was the lack of clouds. Everyone was expecting the probe to pass through three layers of clouds: ammonia at the top, ammonia hydrosufide in the middle, and water clouds below. Did the probe just hit a dry, cloudless spot? Or is there really much less water than expected? Jupiter's dry weather had enormous implications.

Instrument Team	Measurements
Gravity	Detects Doppler shift of radio broadcasts from Juno to Earth in Ka band and X band, to derive small motions of Juno in response to Jupiter's uneven gravity field.
JADE	Measures the angular distribution, energy, and velocity vector of ions (5 eV to 50 KeV) and electrons (100 eV to 100 KeV) present in the aurora regions of Jupiter.
JEDI	Measures fluxes of high-energy ions (20 keV to 1000 keV) and electrons (40 keV to 500 keV) present in the polar magnetosphere of Jupiter.
JIRAM	Maps near-infrared (2 to 5 μm) from upper layers of the atmosphere to a depth of between 50 and 70 km (5 to 7 bars). Provides images of the aurora at 3.4 μm from H_3^+ ions. It also detects methane, water vapor, ammonia, and phosphine.

JunoCAM	A visible light camera/telescope, included to facilitate education and public outreach.
MAG	A Flux Gate Magnetometer (FGM) measures the strength and direction of the magnetic field, while the Advanced Stellar Compass (ASC) monitors the orientation of the magnetometer sensors.
MWR	Measures electromagnetic waves in the microwave range 600 MHz, 1.2 GHz, 2.4 GHz, 4.8 GHz, 9.6 GHz, and 22 GHz, maping the abundance of water and ammonia in the deep layers of the atmosphere up to 200 bar pressure or 500 to 600 km deep.
UVS	A 1024 × 256 micro channel plate detector, it will provide spectral images of the UV auroral emissions in the polar magnetosphere.
WAVES	Measures the radio and plasma spectra in the auroral region.



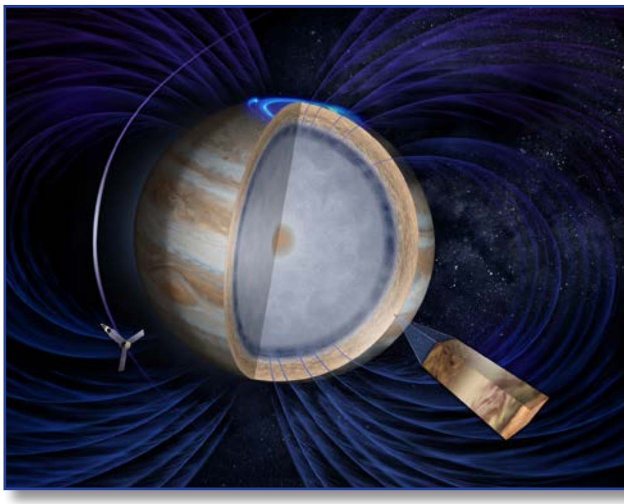
What's the Deal with Water?

Conventional thinking is that the giant planets began their lives as small grains of rock with metal, ice, and volatiles trapped in them. As they bumped into each other, the grains grew larger — first to boulders and then to kilometer-sized planetesimals — eventually forming Earth-sized planetary embryos. Since the giant planets formed beyond the snow line — a hypothetical boundary in the primordial solar nebula, where water was in the form of ice — the snowball embryos could continue to grow until they reached 10–15 Earth masses. Thus, the cores of the giant planets were formed. Since oxygen is the third most abundant element (after hydrogen and helium), water may comprise one-half to two-thirds of the mass of the core. Such a large core then had the ability to gravitationally pull in the most volatile of the gases — hydrogen, helium, and neon — from the surrounding nebula. In the case of Jupiter, it is those gases, mainly hydrogen, that make up most of the planet's mass of 320 Earth masses, the rest being in the heavy elements that formed the core (in astrophysical jargon, all elements greater than the mass of helium, which is four times the mass of hydrogen, are called heavy elements).

Theoretical models give a range of Jupiter's heavy element abundance between 3% and 13% by mass. This is a huge uncertainty. Oxygen is the third most abundant element in the universe and is assumed to comprise half the mass of heavy elements in Jupiter. Pinning down the jovian water abundance — the single most important datum missing in our understanding of solar system formation — is a major priority for not just Jupiter but for all stellar systems.

The entire process of forming Jupiter took between one and five million years, which was just enough time before the solar nebula itself dissipated. The heat of planet formation resulted in the release of volatiles trapped in the core. These gases, plus material captured in the last stages of formation — hydrogen, helium, and neon — formed the atmosphere of Jupiter. Thus, the signatures of the formation of Jupiter — particularly water — are believed to be present in the bulk composition of its atmosphere.

Confused by the Galileo probe's dry descent, planetary scientists clamored to send more probes into Jupiter's atmosphere to find out where the water could be hiding. Scott Bolton and colleagues at the Jet Propulsion Laboratory had a better idea. We all know that microwaves are absorbed by water (that's how a mug of tea is heated in a microwave oven). Since we know Jupiter is hot inside and emits microwave radiation from the deep interior, Bolton thought, "Why not just fly a microwave receiver above the clouds of Jupiter and map out the distribution of water?" Getting close enough to Jupiter to map the microwaves would also enable detailed mapping of gravitational and magnetic fields of the planet. But the obstacle to observing Jupiter's microwave emission from Earth is the same obstacle that presents itself during close orbits of Jupiter: a belt of energetic particles trapped in Jupiter's magnetic field. To conduct sound tests of Jupiter's interior, a spacecraft would need a polar orbit that skims above the atmosphere but ducks under the radiation belts. This became the core of the Juno mission concept.



By flying close to Jupiter the Juno spacecraft will avoid the dangerous radiation belts that surround the planet — and at the same time probe the deep interior, measure the structure and chemistry of Jupiter's atmospheric layers, and map the planet's magnetic field, shown here as blue lines.

In 2005, Bolton's Juno mission was selected as the second mission in NASA's New Frontiers program. Competing with other missions for NASA funding meant that the Juno scientists had to limit their appetite and focus attention on three main objectives: Jupiter's interior, atmosphere, and polar magnetosphere.

Interior — What's Stirring?

Despite numerous space missions that have flown past Jupiter, the planet has kept many of its secrets. Not only do we not know what quantities of heavy elements it contains, we do not know if these heavy elements remain concentrated in a central, solid core. For the past decades textbooks have shown Jupiter as having a small central core of solid rock and ice; an outermost layer of molecular hydrogen; and a large, central volume of atomic hydrogen where the pressure is sufficient to allow protons and electrons to move past each other, enabling strong electrical currents to flow. It is in this large volume of so-called metallic hydrogen where a magnetic field is generated. Jupiter has the second most powerful magnetic dynamo in the solar system (after the Sun's). The workings of Jupiter's dynamo probably bears little resemblance to Earth's small, iron-core dynamo, but is it necessarily like the Sun's dynamo?

Sophisticated computer simulations construct movies of swirling flows driven by primordial internal heat and wrapped up in Jupiter's rotation (the planet's spin period is just shy of 10 hours). But such models depend on knowing how hydrogen (with some unknown mix of heavy elements) behaves at ultra-high pressures (~50 million atmospheres), at hot temperatures (20,000 Kelvin, or 4 times the temperature at the surface of the Sun), and with a density somewhere between that of rock and lead.

Aside: Just how high are the pressures inside Jupiter?

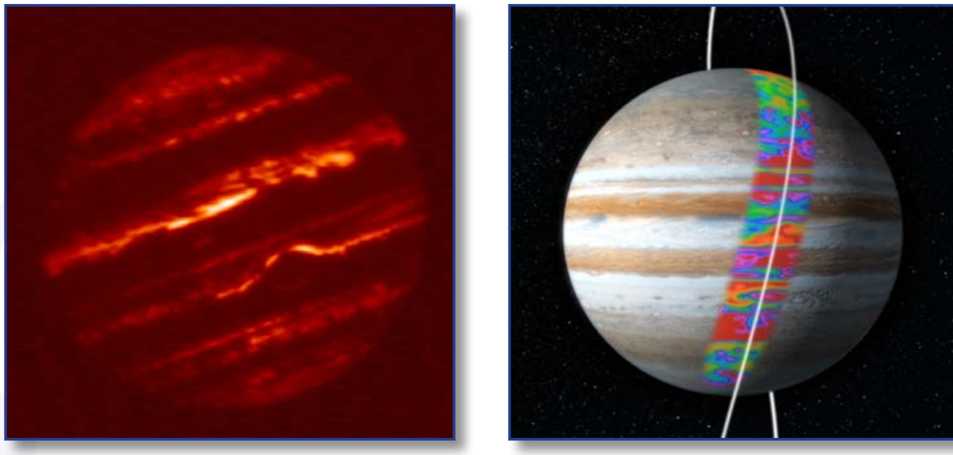
A sense of pressure comes from the force of gravity you feel due to the weight of your body through the area of your feet. Stand on one foot, and you half the area, therefore doubling the pressure. The pressure of the gas in the atmosphere you are breathing is equivalent to the force through your feet if you had four people stacked on your shoulders. That seems hard to believe, but we are used to it. Now think about the pressures at the center of Jupiter — about 50 million times greater. That's equivalent to having 1000 elephants stacked on top of each other with the bottom elephant standing on one foot — balancing on a stiletto heel!

Progress concerning the physical properties of hydrogen compressed to ultra-high pressures comes from zapping hydrogen in the lab with lasers as well as from sophisticated quantum mechanical models. Recent studies of conditions at the center of Jupiter suggest that contrary to the standard textbook picture, the heavy elements could be completely dissolved in the metallic hydrogen and stirred up into a more uniform mixture. While such laboratory studies and increasingly complex dynamo models suggest the range of possibilities, our knowledge of Jupiter's interior will ultimately require three key measurements: (1) a determination of the bulk abundance of heavy elements, (2) mapping the planet's gravity field, and (3) mapping the planet's magnetic field. For the level of accuracy and spatial resolution necessary, these measurements need to be made as close as possible to the planet.

Atmosphere — Where's the Water?

The Galileo probe was carefully designed to determine the abundances of the heavy elements of Jupiter, but for the past 20 years atmospheric scientists have been trying to understand the surprisingly clear, dry "hot spot" into which the Galileo probe seems to have plunged. It was so dry that even at four times the atmospheric pressure at which water clouds were expected, water was still greatly depleted. Images of Jupiter taken from Earth at the time of the Galileo probe's entry show that it plunged into a region between the cloud bands. Andrew Ingersoll, an atmospheric scientist on the Juno team from the California Institute of Technology, describes the fierce downdraft that engulfed the probe: "If you could ride a balloon into one of the hot spots, you would experience a vertical drop of 60 miles [97 kilometers] — more than 10 times the height of Mt. Everest."

Look at Jupiter with a small telescope or binoculars and you will see white and orange cloud bands and its enigmatic Great Red Spot. Reflected sunlight at visible wavelengths shows the white clouds of ammonia (NH_3) and orange clouds of ammonia hydrosulfide (NH_4SH). The coloring agent has puzzled astronomers for many decades. Current ideas are the irradiation of the atmospheric gases producing sulfur compounds that are mixed in with NH_4SH. But maybe next year there will be other ideas. Looking at longer wavelengths, in the infrared (IR), the light is not reflected from the Sun but rather emitted from hotter gases below the upper cloud decks. In IR, the cold high-altitude ammonia clouds look black, with bright



Left: Jupiter observed in the infared from Earth, showing variations in heat coming from inside. Right: Microwaves go deeper. Mapping the absorption of microwave emissions by the atmospheric gases will be performed using six wavebands represented by colors in this schematic.

IR escaping from below between the clouds. If we look at even longer wavelengths — in the microwave region — we probe deeper into the atmosphere.

The Juno microwave radiometers (MWR) have six wavelength bands [from 1.37 centimeters (0.5 inches) to 50 centimeters (20 inches)] that are designed to determine the abundance of water to at least 100 bars, which is well below the expected level of condensation of water. This should ensure the determination of the oxygen elemental abundance, which comes from water. The full complement of the elemental data that includes the Juno-derived abundance of oxygen and nitrogen (from ammonia) — added to other data from the Galileo probe — will be key to understanding how Jupiter formed, how it acquired its atmosphere, and how it evolved over time.

While Juno's MWR detectors are mapping the spatial distribution of materials below the clouds, other Juno instruments will make complementary observations of what's happening above, at visible [Juno Camera (JunoCam)], ultraviolet [Ultraviolet Spectrograph (UVS)], and infrared [Jovian Infrared Auroral Mapper (JIRAM)] wavelengths. Juno's polar orbit provides our first pictures looking directly down on the poles of Jupiter. Does the pattern of alternative winds — the belts and zones — persist all the way to the poles?

Magnetosphere — What Triggers Jupiter's Intense Aurora?

Jupiter's strong magnetic field makes the planet's magnetosphere the largest object within the solar system. On the sunward side, the magnetosphere extends for typical distances 50–100 times the radius of Jupiter. On Jupiter's nightside, its magnetotail stretches beyond the orbit of Saturn.

The vast and complicated magnetosphere of Jupiter was first detected in 1954, before James Van Allen's Explorer 1 discovery of Earth's radiation belts, via bursts of radio emission at wavelengths of tens of meters. Subsequent radio observations at shorter (tenths of meters) wavelengths revealed emission from trapped electrons. These early radio measurements showed that Jupiter has a strong magnetic field (opposite in polarity to Earth's) tilted about 10° from the spin axis, and that energetic (>MeV) electrons

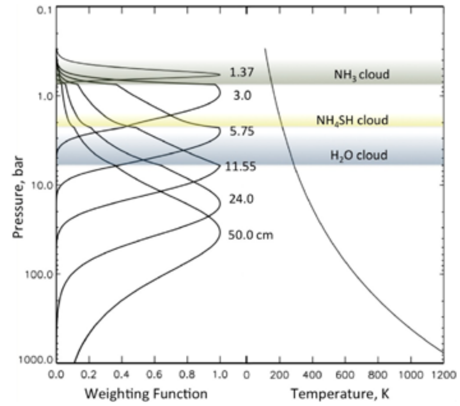
Juno's polar orbit takes it over the polar region where instruments will measure the electrical currents, electric waves, and charged particles that are accelerated in Jupiter's magnetosphere and bombard Jupiter's atmosphere, generating Jupiter's intense aurora — seen here by the Hubble Space Telescope from Earth orbit.

are trapped near the equator close to the planet. These very energetic particles pose a formidable hazard for spacecraft exploring close to Jupiter.

The peculiar role of Io was first pointed out in the 1964 observations that bursts of radio emission were modulated by the position of the moon along its 42-hour orbit around Jupiter. The magnetometers and particle detectors on Pioneer 10 (1973) and Pioneer 11 (1974) exposed the vastness of Jupiter's magnetosphere and made *in situ* measurements of energetic ions and electrons. The Voyager 1 flyby in 1979 revealed Io's prodigious volcanic activity, thus explaining why this innermost Galilean moon plays such a strong role. Over a ton per second of Io's sulfur dioxide (SO_2) atmosphere escapes the satellite. The escaping neutral molecules are dissociated into sulfur and oxygen atoms, ionized and trapped by the magnetic field. The resulting dense torus of plasma — a donut of charged particles — roughly co-rotates with Jupiter's ~10-hour spin period. The ions of sulfur and oxygen are excited by colliding electrons and radiate ~1.5 terawatts of ultraviolet (UV) emission.

Coupling of the magnetospheric plasma to Jupiter's rotating atmosphere dominates the dynamics of the magnetosphere. Associated with the electrical currents that couple the magnetospheric and ionospheric plasmas are intense auroral emissions that span the spectrum from X-rays to radio waves. Dramatic images from Hubble's UV cameras show the persistent structures of Jupiter's intense aurora, excited by energetic electrons bombarding the molecular hydrogen atmosphere. Groundbased IR observations of emissions from an unusual molecular ion, H_3^+, revealed an auroral spot at the foot of the magnetic field line connected to Io. This must be the electrical connection between Io and the planet that's the source of the bursts that radio astronomers have been monitoring all these decades. Hubble images added auroral spots associated with Europa and Ganymede, indicating further electrical current systems. Earth-orbiting X-ray telescopes found Jupiter to be emitting at short wavelengths with a spectrum that suggested energetic ions are also bombarding the atmosphere.

So, we see that a variety of auroral emissions indicating beams of energetic electrons and ions are shooting into Jupiter's atmosphere. We can guess that the processes that accelerate these charged particles are likely similar to the processes occurring above Earth's aurora. Jupiter's magnetosphere has been traversed by the Ulysses (1992), Cassini (2000), and New Horizons (2007) spacecraft, and the 33 orbits of Galileo (1995–2003) around Jupiter mapped out the equatorial magnetospheric structures and monitored their temporal variability. But no spacecraft has yet to fly over Jupiter's poles. Thus, the Juno spacecraft was loaded up with instruments that will measure the charged particles, magnetic fields, and electric



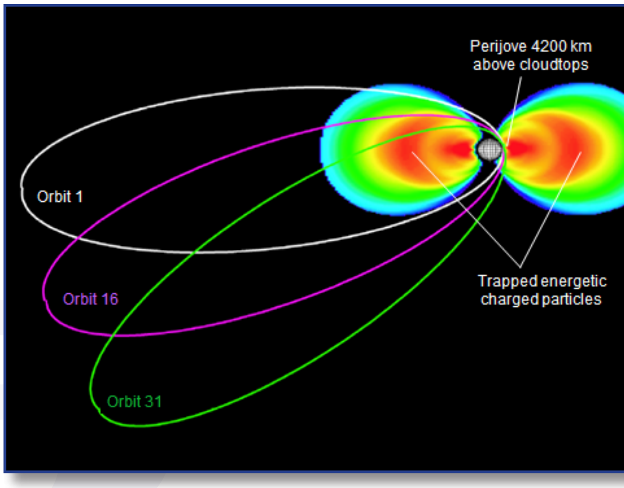
In the visible part of the spectrum (left), reflected sunlight shows white clouds of ammonia and orange clouds colored with sulfur as seen by Voyager in 1979. Measuring microwaves at six different absorption bands (curved lines in plot at right), Juno will detect how much of the emission from the interior is absorbed by the three different cloud layers at the different wavelengths shown.

waves as it flies for the first time through the magnetic field lines where we think the auroral particles are generated. At the same time, the UVS, JIRAM, and JunoCAM will look down on the auroral emissions excited where the same magnetic field lines intersect the planet. I must admit that I am a bit nervous for Juno — those field lines are carrying millions of amps of electrical current . . . it's a scary place to explore!

The Juno Mission

The Juno spacecraft is impressive. The three solar panels are each 30 feet long (approximately 9 meters). At Jupiter (where sunlight is 25 times weaker than at Earth), they generate 400 watts of power. Roughly half of this power will keep the spacecraft warm, while the rest drives the spacecraft and science instruments. The 8000-pound (3629-kilogram) spacecraft cartwheels at 2 rpm. Such an operation makes snapping pictures tricky, but this spin of the spacecraft allows the instruments to sweep the sky every 30 seconds.

Juno was launched from Cape Canaveral on August 5, 2011. Using a gravity boost from an Earth flyby on October 9, 2013, Juno will arrive at Jupiter on July 4 of this year. Firing its engines close to the planet will put the spacecraft into a polar orbit. The first couple of orbits are planned to last 53 days each, allowing the Juno team to get used to operating the spacecraft at Jupiter. Then, in mid-October, Juno will start a sequence of two-week orbits. On each orbit the spacecraft makes a two-hour dash over the north pole, ducks under the radiation belt, skims 4200 kilometers (2610 miles) above the clouds, then zooms back out over the south pole. For the remainder of the 14 days the spacecraft sends the data stored during the intense perijove period back to Earth and samples the magnetospheric environment away from the planet. Such an orbit would be great if we could maintain it. But Jupiter's 10-hour rotation swells its equator by 6% compared to the poles. Jupiter's equatorial bulge means that Juno's original orbit will inevitably change, tilting the orbit by about a degree per orbit. This means that sooner or later Juno will enter the radiation belt. We have protected the electronics as best we can by encasing them in a titanium vault. But it is quite likely that bathing sensitive electronics in 10-MeV electrons will cause damage. We are hoping for 35 orbits — even a handful would revolutionize our understanding of Jupiter — and who knows; perhaps Juno will survive much longer.



The gravity of Jupiter's equatorial bulge pulls Juno's orbit down below the equator, eventually dragging the spacecraft deeper into the intense radiation belt.

While taking pretty pictures is not a main goal of Juno science, JunoCAM was added to increase public involvement in the mission. Unlike other NASA missions, the public can vote on what pictures they want JunoCAM to take by visiting *http://www.missionjuno.swri.edu/junocam*. The JunoCAM website also solicits images of Jupiter that have been taken with personal telescopes. Hundreds of images have already been posted. These images will allow scientists studying the cloud structures observed with Juno's instruments to get the context of those measurements: What was happening in those cloud bands? Where were the dark spots? How were the winds blowing before, during, and after each Juno orbit?

For more information about the mission, visit *http://www.missionjuno.swri.edu* or *http://www.nasa.gov/juno*. Get ready, Jupiter; Juno's coming!

About the Author:

Fran Bagenal, a researcher at the University of Colorado, Boulder, is a co-investigator on the Juno mission. She also co-chairs Juno's Magnetospheric Working Group and Science Planning Working Group. The focus of her research has been the synthesis of data analysis and theory in the study of space plasmas, and she has also studied planetary magnetospheres. In addition to her work on the Juno mission, Bagenal is a co-investigator on the Voyager Plasma Science (PLS) experiment and has worked with colleagues at the Massachusetts Institute of Technology in analyzing plasma data obtained in the magnetospheres of Jupiter, Saturn, Uranus, and Neptune. She is also a science team member of the Deep Space 1 mission and team leader of the plasma investigations on the New Horizons mission to Pluto. She thanks Sushil K. Atreya (University of Michigan) for assistance with this article.

About the Cover:

Launched from Earth in 2011, the Juno spacecraft — powered by three 30-foot-long (approximately 9 meters long) solar panels — will arrive at Jupiter on July 4 to begin its 18-month exploration of the giant gas planet. Credit: NASA/JPL-Caltech.

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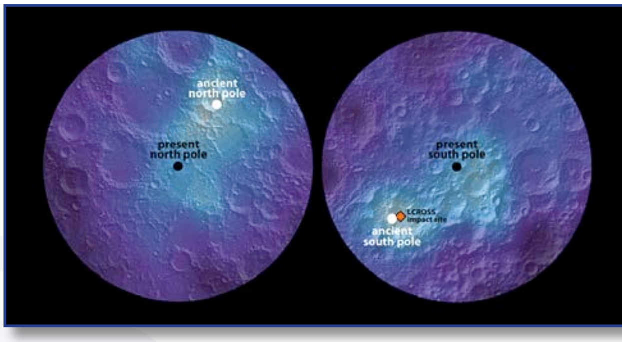
Ancient Polar Ice Reveals Tilting of Earth's Moon



This polar hydrogen map of the Moon's northern and southern hemispheres identifies the location of the Moon's ancient and present day poles. In the image, the lighter areas show higher concentrations of hydrogen and the darker areas show lower concentrations. Credits: James Keane/University of Arizona; Richard Miller, University of Alabama at Huntsville.

Did the "Man in the Moon" look different from ancient Earth? New NASA-funded research provides evidence that the spin axis of Earth's Moon shifted by about 5° roughly three billion years ago. The evidence of this motion is recorded in the distribution of ancient lunar ice, evidence of delivery of water to the early solar system. "The same face of the Moon has not always pointed toward Earth," said Matthew Siegler of the Planetary Science Institute in Tucson, Arizona, lead author of a paper in the March 23 issue of the journal *Nature*. "As the axis moved, so did the face of the 'Man in the Moon.' He sort of turned his nose up at the Earth."

Water ice can exist on Earth's Moon in areas of permanent shadow. If ice on the Moon is exposed to direct sunlight it evaporates into space. Authors of the *Nature* article show evidence that a shift of the lunar spin axis billions of years ago enabled sunlight to creep into areas that were once shadowed and likely previously contained ice. The researchers found that the ice that survived this shift effectively "paints" a path along which the axis moved. They matched the path with models predicting where the ice could remain stable and inferred the Moon's axis had moved by approximately 5°. This is the first physical evidence that the Moon underwent such a dramatic change in orientation and implies that much of the polar ice on the Moon is billions of years old.

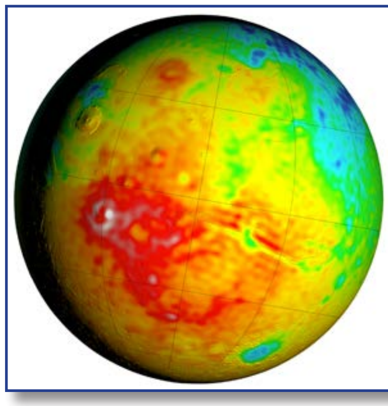
"The new findings are a compelling view of the Moon's dynamic past," said Dr. Yvonne Pendleton, director of NASA's Solar System Exploration Research Virtual Institute (SSERVI), which supports lunar and planetary science research to advance human exploration of the solar system through scientific discovery. "It is wonderful to see the results of several missions pointing to these insights." The authors analyzed data from several NASA missions, including Lunar Prospector, Lunar Reconnaissance Orbiter (LRO), Lunar Crater and Observation Sensing Satellite (LCROSS), and the Gravity Recovery and Interior Laboratory (GRAIL) to build the case for a change in the Moon's orientation. Topography from the Lunar Orbiter Laser Altimeter (LOLA) and thermal measurements from the Diviner lunar radiometer — both on LRO — are used to aid the interpretation of Lunar Prospector neutron data that support the polar wander hypothesis.

Siegler noticed that the distribution of ice observed at each of the lunar poles appeared to be more related to each other than previously thought. Upon further investigation, Siegler and co-author Richard Miller of the University of Alabama at Huntsville discovered that ice concentrations were displaced from each pole by the same distance, but in exactly opposite directions, suggesting the spin axis in the past was tilted from what we see today. A change in the tilt means that some of the ice deposited long ago has since evaporated as it was exposed to sunlight, but those areas that remain in permanent shadow between the old orientation and the new one retain their ice, and thus indicate what happened.

A planetary body can shift on its axis when there is a very large change in mass distribution. Co-author James Keane, of the University of Arizona in Tucson, modeled the way changes in the lunar interior would have affected the Moon's spin and tilt. In doing so, he found the Procellarum region on the lunar nearside was the only feature that could match the direction and amount of change in the axis indicated by the ice distributions near the poles. Furthermore, concentrations of radioactive material in the Procellarum region are sufficient to have heated a portion of the lunar mantle, causing a density change significant enough to reorient the Moon.

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

New Gravity Map Gives Best View Yet Inside Mars



This Mars map shows variations in thickness of the planet's crust, the relatively thin surface layer overlying the mantle of the planet. It shows unprecedented detail derived from new mapping of variations in Mars' gravitational pull on orbiters. Credit: NASA/GSFC/Scientific Visualization Studio.

A new map of Mars' gravity made with three NASA spacecraft is the most detailed to date, providing a revealing glimpse into the hidden interior of the Red Planet. "Gravity maps allow us to see inside a planet, just as a doctor uses an X-ray to see inside a patient," said Antonio Genova of the Massachusetts Institute of Technology (MIT), Cambridge. "The new gravity map will be helpful for future Mars exploration, because better knowledge of the planet's gravity anomalies helps mission controllers insert spacecraft more precisely into orbit about Mars. Furthermore, the improved resolution of our gravity map will help us understand the still-mysterious formation of specific regions of the planet." Genova, who is affiliated with MIT but is located at NASA's Goddard Space Flight Center in Greenbelt, Maryland, is the lead author of a paper on this research published online March 5 in the journal *Icarus*.

The improved resolution of the new gravity map suggests a new explanation for how some features formed across the boundary that divides the relatively smooth northern lowlands from heavily cratered southern highlands. Also, the team confirmed that Mars has a liquid outer core of molten rock by analyzing tides in the martian crust and mantle caused by the gravitational pull of the Sun and the two moons of Mars. Finally, by observing how Mars' gravity changed over 11 years — the period of an entire cycle of solar activity — the team inferred the massive amount of carbon dioxide that freezes out of the atmosphere onto a martian polar ice cap when it experiences winter. They also observed how that mass moves between the south pole and the north pole with the change of season in each hemisphere.

The map was derived using Doppler and range tracking data collected by NASA's Deep Space Network from three NASA spacecraft in orbit around Mars: Mars Global Surveyor (MGS), Mars Odyssey (ODY), and the Mars Reconnaissance Orbiter (MRO). Like all planets, Mars is lumpy, which causes the gravitational pull felt by spacecraft in orbit around it to change. For example, the pull will be a bit stronger over a mountain, and slightly weaker over a canyon.

Slight differences in Mars' gravity changed the trajectory of the NASA spacecraft orbiting the planet, which altered the signal being sent from the spacecraft to the Deep Space Network. These small fluctuations in the orbital data were used to build a map of the martian gravity field. The gravity field was recovered using about 16 years of data that were continuously collected in orbit around Mars. However, orbital changes from uneven gravity are tiny, and other forces that can perturb the motion of the spacecraft had to be carefully accounted for, such as the force of sunlight on the spacecraft's solar panels and drag from the Red Planet's thin upper atmosphere. It took two years of analysis and computer modeling to remove the motion not caused by gravity.

"With this new map, we've been able to see gravity anomalies as small as about 62 miles [100 kilometers] across, and we've determined the crustal thickness of Mars with a resolution of almost 75 miles [around 120 kilometers]," said Genova. "The better resolution of the new map helps interpret how the crust of the planet changed over Mars' history in many regions."

For example, an area of lower gravity between Acidalia Planitia and Tempe Terra was interpreted before as a system of buried channels that delivered water and sediments from Mars' southern highlands into the northern lowlands billions of years ago when the martian climate was wetter than it is today. The new map reveals that this low gravity anomaly is definitely larger and follows the boundary between the highlands and the lowlands. This system of gravity troughs is unlikely to be only due to buried channels because in places the region is elevated above the surrounding plains. The new gravity map shows that some of these features run perpendicular to the local topography slope, against what would have been the natural downhill flow of water.

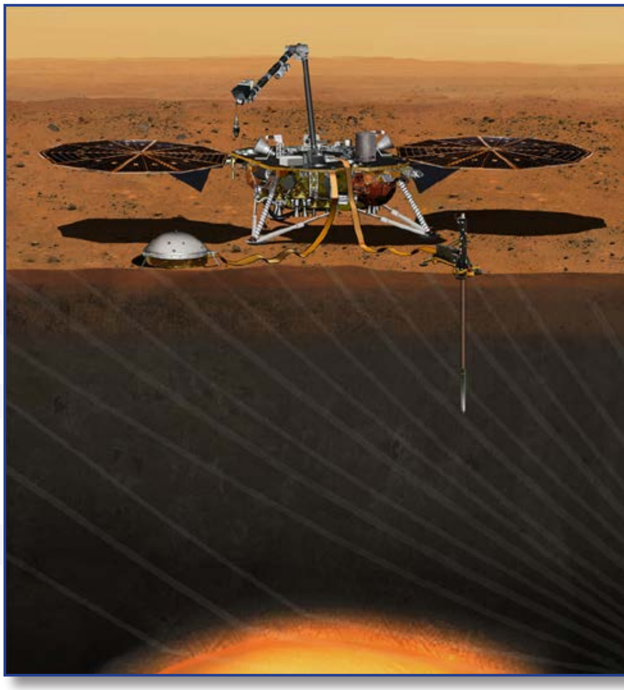
An alternative explanation is that this anomaly may be a consequence of a flexure or bending of the lithosphere — the strong, outermost layer of the planet — due to the formation of the Tharsis region. Tharsis is a volcanic plateau on Mars thousands of miles across with the largest volcanos in the solar system. As the Tharsis volcanos grew, the surrounding lithosphere buckled under their immense weight.

The new gravity field also allowed the team to confirm indications from previous gravity solutions that Mars has a liquid outer core of molten rock. The new gravity solution improved the measurement of the martian tides, which will be used by geophysicists to improve the model of Mars' interior.

Changes in martian gravity over time have been previously measured using the MGS and ODY missions to monitor the polar ice caps. For the first time, the team used MRO data to continue monitoring their mass. The team has determined that when one hemisphere experiences winter, approximately 3 to 4 trillion tons of carbon dioxide freezes out of the atmosphere onto the northern and southern polar caps, respectively. This is about 12% to 16% of the mass of the entire martian atmosphere. NASA's Viking missions first observed this massive seasonal precipitation of carbon dioxide. The new observation confirms numerical predictions from the Mars Global Reference Atmospheric Model — 2010.

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

NASA Targets May 2018 for Launch of Mars InSight Mission



NASA has set a new launch opportunity, beginning May 5, 2018, for the InSight mission to Mars. InSight is the first mission dedicated to investigating the deep interior of Mars. Credit: NASA/JPL-Caltech.

NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission to study the deep interior of Mars is targeting a new launch window that begins May 5, 2018, with a Mars landing scheduled for November 26, 2018. InSight's primary goal is to help us understand how rocky planets — including Earth — formed and evolved. The spacecraft had been on track to launch this month until a vacuum leak in its prime science instrument prompted NASA in December to suspend preparations for launch.

InSight project managers recently briefed officials at NASA and France's space agency, Centre National d'Études Spatiales (CNES), on a path forward; the proposed plan to redesign the science instrument was accepted in support of a 2018 launch. "The science goals of InSight are compelling, and the NASA and CNES plans to overcome the technical challenges are sound," said John Grunsfeld, associate administrator for NASA's Science Mission Directorate in Washington. "The quest to understand the interior of Mars has been a longstanding goal of planetary scientists for decades. We're excited to be back on the path for a launch, now in 2018."

NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, will redesign, build, and conduct qualifications of the new vacuum enclosure for the Seismic Experiment for Interior Structure (SEIS), the component that failed in December. CNES will lead instrument level integration and test activities, allowing the InSight Project to take advantage of each organization's proven strengths. The two agencies have worked closely together to establish a project schedule that accommodates these plans, and scheduled interim reviews over the next six months to assess technical progress and continued feasibility. The cost of the two-year delay is being assessed, and an estimate is expected in August, once arrangements with the launch vehicle provider have been made.

The seismometer instrument's main sensors need to operate within a vacuum chamber to provide the exquisite sensitivity needed for measuring ground movements as small as half the radius of a hydrogen atom. The rework of the seismometer's vacuum container will result in a finished, thoroughly tested instrument in 2017 that will maintain a high degree of vacuum around the sensors through rigors of launch, landing, deployment, and a two-year prime mission on the surface of Mars.

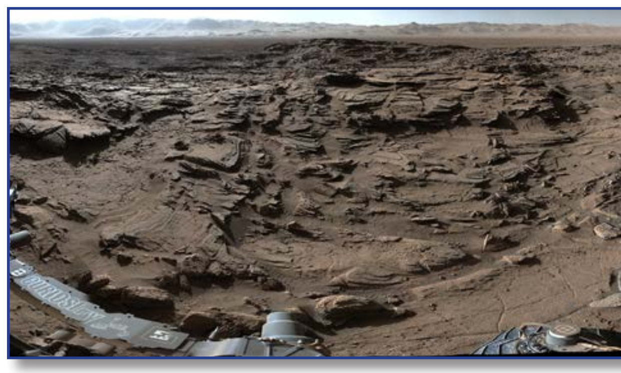
The InSight mission draws upon a strong international partnership led by Principal Investigator Bruce Banerdt of JPL. The lander's Heat Flow and Physical Properties Package is provided by the German Aerospace Center (DLR). This probe will hammer itself to a depth of about 5 meters (16 feet) into the ground beside the lander.

The InSight spacecraft, including cruise stage and lander, was delivered to Vandenberg Air Force Base, California, in December 2015 in preparation for launch, and returned to Lockheed Martin's Colorado facility last month for storage until spacecraft preparations resume in 2017.

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

Curiosity Mars Rover Crosses Rugged Plateau

NASA's Curiosity Mars rover has nearly finished crossing a stretch of the most rugged and difficult-to-navigate terrain encountered during the mission's 44 months on Mars. The rover climbed onto the "Naukluft Plateau" of lower Mount Sharp in early March after spending several weeks investigating sand dunes. The plateau's sandstone bedrock has been carved by eons of wind erosion into ridges and knobs. The path of 400 meters (about a quarter mile) westward across it is taking Curiosity toward smoother surfaces leading to geological layers of scientific interest farther uphill.



This 360° panorama from the Mastcam on NASA's Curiosity Mars rover shows the rugged surface of "Naukluft Plateau" plus upper Mount Sharp at right and part of the rim of Gale Crater. Credit: NASA/JPL-Caltech/MSSS.

The roughness of the terrain on the plateau raised concern that driving on it could be especially damaging to Curiosity's wheels, as was terrain Curiosity crossed before reaching the base of Mount Sharp. Holes and tears in the rover's aluminum wheels became noticeable in 2013. The rover team responded by adjusting the long-term traverse route, revising how local terrain is assessed and refining how drives are planned. Extensive Earth-based testing provided insight into wheel longevity.

The rover team closely monitors wear and tear on Curiosity's six wheels. "We carefully inspect and trend the condition of the wheels," said Steve Lee, Curiosity's deputy project manager at NASA's Jet Propulsion Laboratory, Pasadena, California. "Cracks and punctures have been gradually accumulating at the pace we anticipated, based on testing we performed at JPL. Given our longevity projections, I am confident these wheels will get us to the destinations on Mount Sharp that have been in our plans since before landing." Inspection of the wheels after crossing most of the Naukluft Plateau has indicated that, while the terrain presented challenges for navigation, driving across it did not accelerate damage to the wheels.

On Naukluft Plateau, the rover's Mast Camera has recorded some panoramic scenes from the highest viewpoints Curiosity has reached since its August 2012 landing on the floor of Gale Crater on Mars. Examples are available online at *http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA20332* and *http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA20333*. The scenes show wind-sculpted textures in the sandstone bedrock close to the rover, and Gale Crater's rim rising above the crater floor in the distance. Mount Sharp stands in the middle of the crater, which is about 154 kilometers (96 miles) in diameter.

The next part of the rover's route will return to a type of lake-deposited mudstone surface examined previously. Farther ahead on lower Mount Sharp are three geological units that have been key destinations for the mission since its landing site was selected. One of the units contains an iron-oxide mineral called hematite, which was detected from orbit. Just above it lies a band rich in clay minerals, then a series of layers that contain sulfur-bearing minerals called sulfates. By examining them with Curiosity, researchers hope to gain a better understanding of how long ancient environmental conditions remained favorable for microbial life, if it was ever present on Mars, before conditions became drier and less favorable.

Each of Curiosity's six wheels is about 50 centimeters (20 inches) in diameter and 40 centimeters (16 inches) wide, milled out of solid aluminum. Most of the wheel's circumference is a metallic skin that is about half the thickness of a U.S. dime. Nineteen zigzag-shaped treads, called grousers, extend about three-fourths of a centimeter (about a quarter inch) outward from the skin of each wheel. The grousers bear much of the rover's weight and provide most of the traction and ability to traverse over uneven terrain.

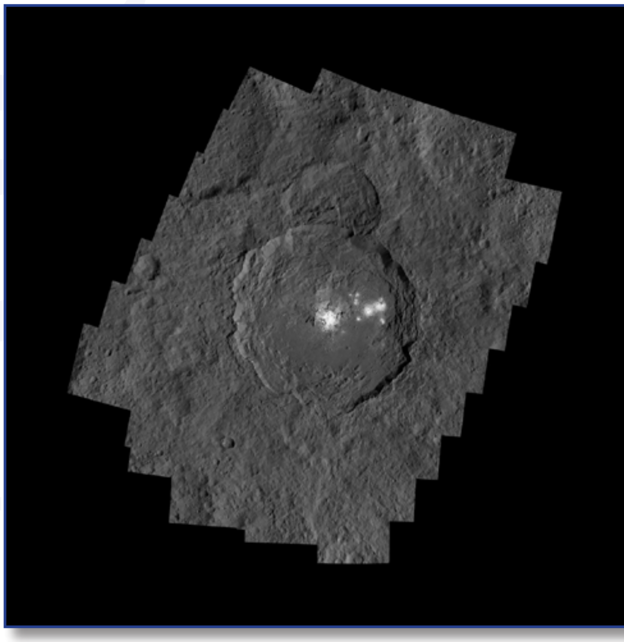
The holes seen in the wheels so far perforate only the skin. Wheel-monitoring images obtained every 500 meters (547 yards) have not yet shown any grouser breaks on Curiosity. Earth-based testing examined long-term wear characteristics and the amount of damage a rover wheel can sustain before losing its usefulness for driving. The tests indicate that when three grousers on a wheel have broken, that wheel has reached about 60% of its useful mileage.

At a current odometry of 12.7 kilometers (7.9 miles) since its August 2012 landing, Curiosity's wheels are projected to have more than enough life remaining to investigate the hematite, clay, and sulfate units ahead, even in the unlikely case that up to three grousers break soon. The driving distance to the start of the sulfate-rich layers is roughly 7.5 kilometers (4.7 miles) from the rover's current location.

Curiosity reached the base of Mount Sharp in 2014 after fruitfully investigating outcrops closer to its landing site and then trekking to the layered mountain. For more information, visit *http://mars.jpl.nasa.gov/msl*.

Bright Spots and Color Differences Revealed on Ceres

Scientists from NASA's Dawn mission unveiled new images from the spacecraft's lowest orbit at Ceres, including highly anticipated views of young craters, including Occator Crater, during the 47th Lunar and Planetary Science Conference (LPSC) in The Woodlands, Texas, on March 22.



Occator Crater, measuring 57 miles (92 kilometers) across and 2.5 miles (4 kilometers) deep, contains the brightest area on Ceres. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/PSI.

Occator Crater, measuring 57 miles (92 kilometers) across and 2.5 miles (4 kilometers) deep, contains the brightest area on Ceres, the dwarf planet that Dawn has explored since early 2015. The latest images, taken from 240 miles (385 kilometers) above the surface of Ceres, reveal a dome in a smooth-walled pit in the bright center of the crater. Numerous linear features and fractures crisscross the top and flanks of this dome. Prominent fractures also surround the dome and run through smaller, bright regions found within the crater.

"Before Dawn began its intensive observations of Ceres last year, Occator Crater looked to be one large bright area. Now, with the latest close views, we can see complex features that provide new mysteries to investigate," said Ralf Jaumann, planetary scientist and Dawn co-investigator at the German Aerospace Center (DLR) in Berlin. "The intricate geometry of the crater interior suggests geologic activity in the recent past, but we will need to complete detailed geologic mapping of the crater in order to test hypotheses for its formation."

The team also released an enhanced color map of the surface of Ceres, highlighting the diversity of surface materials and their relationships to surface morphology. Scientists have been studying the shapes of craters and their distribution with great interest. Ceres does not have as many large impact basins as scientists expected, but the number of smaller craters generally matches their predictions. The blue material highlighted in the color map is related to flows, smooth plains, and mountains, which appear to be very young surface features.

"Although impact processes dominate the surface geology on Ceres, we have identified specific color variations on the surface indicating material alterations that are due to a complex interaction of the impact process and the subsurface composition," Jaumann said. "Additionally, this gives evidence for a subsurface layer enriched in ice and volatiles."

Data relevant to the possibility of subsurface ice is also emerging from Dawn's Gamma Ray and Neutron Detector (GRaND), which began acquiring its primary dataset in December. Neutrons and gamma rays produced by cosmic-ray interactions with surface materials provide a fingerprint of Ceres' chemical makeup. The measurements are sensitive to elemental composition of the topmost yard (meter) of the regolith.

In Dawn's lowest-altitude orbit, the instrument has detected fewer neutrons near the poles of Ceres than at the equator, which indicates increased hydrogen concentration at high latitudes. As hydrogen is a principal constituent of water, water ice could be present close to the surface in polar regions. "Our analyses will test a longstanding prediction that water ice can survive just beneath Ceres' cold, high-latitude surface for billions of years," said Tom Prettyman, the lead for GRaND and Dawn co-investigator at the Planetary Science Institute, Tucson, Arizona.

But the subsurface does not have the same composition all over Ceres, according to data from the visible and infrared mapping spectrometer (VIR), a device that looks at how various wavelengths of sunlight are reflected by the surface, allowing scientists to identify minerals. Haulani Crater in particular is an intriguing example of how diverse Ceres is in terms of its surface material composition. This irregularly shaped crater, with its striking bright streaks of material, shows a different proportion of surface materials than its surroundings when viewed with the VIR instrument. While the surface of Ceres is mostly made of a mixture of materials containing carbonates and phyllosilicates, their relative proportion varies across the surface.

"False-color images of Haulani show that material excavated by an impact is different than the general surface composition of Ceres. The diversity of materials implies either that there is a mixed layer underneath, or that the impact itself changed the properties of the materials," said Maria Cristina de Sanctis, the VIR instrument lead scientist, based at the National Institute of Astrophysics, Rome.

Dawn scientists also reported at LPSC that the VIR instrument has detected water at Oxo Crater, a young, 6-mile-wide (9-kilometer-wide) feature in Ceres' northern hemisphere. This water could be bound up in minerals or, alternatively, it could take the form of ice. Jean-Philippe Combe of the Bear Fight Institute, Winthrop, Washington, said that this water-bearing material could have been exposed during a landslide or an impact — perhaps even a combination of the two events. Oxo is the only place on Ceres where water has been detected at the surface so far. Dawn will continue to observe this area.

Dawn made history last year as the first mission to reach a dwarf planet, and the first to orbit two distinct extraterrestrial targets — both of them in the main asteroid belt between Mars and Jupiter. The mission conducted extensive observations of Vesta during its 14-month orbit there in 2011–2012.

"We're excited to unveil these beautiful new images, especially Occator, which illustrate the complexity of the processes shaping Ceres' surface. Now that we can see Ceres' enigmatic bright spots, surface minerals and morphology in high resolution, we're busy working to figure out what processes shaped this unique dwarf planet. By comparing Ceres with Vesta, we'll glean new insights about the early solar system," said Carol Raymond, deputy principal investigator for the Dawn mission, based at NASA's Jet Propulsion Laboratory, Pasadena, California.

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

Europa's Ocean May Have An Earthlike Chemical Balance

A new NASA study modeling conditions in the ocean of Jupiter's moon Europa suggests that the necessary balance of chemical energy for life could exist there, even if the moon lacks volcanic hydrothermal activity. Europa is strongly believed to hide a deep ocean of salty liquid water beneath its icy shell. Whether the jovian moon has the raw materials and chemical energy in the right proportions to support biology is a topic of intense scientific interest. The answer may hinge on whether Europa has environments where chemicals are matched in the right proportions to power biological processes. Life on Earth exploits such niches.

In a new study, scientists at NASA's Jet Propulsion Laboratory (JPL) compared Europa's potential for producing hydrogen and oxygen with that of Earth, through processes that do not directly involve volcanism. The balance of these two elements is a key indicator of the energy available for life. The study found that the amounts would be comparable in scale; on both worlds, oxygen production is about 10 times higher than hydrogen production.

This enhanced-color view from NASA's Galileo spacecraft shows an intricate pattern of linear fractures on the icy surface of Jupiter's moon Europa. Credit: NASA/JPL-Caltech/SETI Institute.

The work draws attention to the ways that Europa's rocky interior may be much more complex and possibly Earthlike than people typically think, according to Steve Vance, a planetary scientist at JPL and lead author of the study. "We're studying an alien ocean using methods developed to understand the movement of energy and nutrients in Earth's own systems. The cycling of oxygen and hydrogen in Europa's ocean will be a major driver for Europa's ocean chemistry and any life there, just as it is on Earth." Ultimately, Vance and colleagues want to also understand the cycling of life's other major elements in the ocean: carbon, nitrogen, phosphorus, and sulfur.

As part of their study, the researchers calculated how much hydrogen could potentially be produced in Europa's ocean as seawater reacts with rock, in a process called serpentinization. In this process, water percolates into spaces between mineral grains and reacts with the rock to form new minerals, releasing hydrogen in the process. The researchers considered how cracks in Europa's seafloor likely open up over time, as the moon's rocky interior continues to cool following its formation billions of years ago. New cracks expose fresh rock to seawater, where more hydrogen-producing reactions can take place.

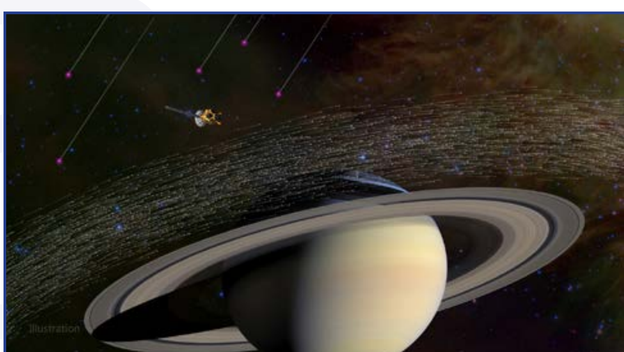
In Earth's oceanic crust, such fractures are believed to penetrate to a depth of 5 to 6 kilometers (3 to 4 miles). On present-day Europa, the researchers expect water could reach as deep as 25 kilometers (15 miles) into the rocky interior, driving these key chemical reactions throughout a deeper fraction of Europa's seafloor.

The other half of Europa's chemical-energy-for-life equation would be provided by oxidants — oxygen and other compounds that could react with the hydrogen — being cycled into the europan ocean from the icy surface above. Europa is bathed in radiation from Jupiter, which splits apart water ice molecules to create these materials. Scientists have inferred that Europa's surface is being cycled back into its interior, which could carry oxidants into the ocean.

"The oxidants from the ice are like the positive terminal of a battery, and the chemicals from the seafloor, called reductants, are like the negative terminal. Whether or not life and biological processes complete the circuit is part of what motivates our exploration of Europa," said Kevin Hand, a planetary scientist at JPL who co-authored the study.

Europa's rocky, neighboring jovian moon, Io, is the most volcanically active body in the solar system, due to heat produced by the stretching and squeezing effects of Jupiter's gravity as it orbits the planet. Scientists have long considered it possible that Europa might also have volcanic activity, as well as hydrothermal vents, where mineral-laden hot water would emerge from the sea floor. According to Vance, researchers previously speculated that volcanism is paramount for creating a habitable environment in Europa's ocean. If such activity is not occurring in its rocky interior, the thinking goes, the large flux of oxidants from the surface would make the ocean too acidic, and toxic, for life. "But actually, if the rock is cold, it's easier to fracture. This allows for a huge amount of hydrogen to be produced by serpentinization that would balance the oxidants in a ratio comparable to that in Earth's oceans," he said. The results are published online in the journal *Geophysical Research Letters*.

NASA is currently formulating a mission to explore Europa and investigate in depth whether the icy moon might be habitable. This new model is part of a large body of evidence that is guiding the mission's development. Some time in the 2020s, NASA would send a highly capable, radiation-tolerant spacecraft into a long, looping orbit around Jupiter to perform repeated close flybys of Europa. During these flybys, the mission would take high-resolution images; determine the composition of the icy moon's surface and faint atmosphere; and investigate its ice shell, ocean, and interior. For more information, visit *http://www.nasa.gov/europa.*



Of the millions of dust grains Cassini has sampled at Saturn, a few dozen appear to have come from beyond our solar system. Scientists believe these special grains have interstellar origins because they moved much faster and in different directions compared to dusty material native to Saturn. Credit: NASA/JPL-Caltech.

Saturn Spacecraft Samples Interstellar Dust

NASA's Cassini spacecraft has detected the faint but distinct signature of dust coming from beyond our solar system. The research, led by a team of Cassini scientists primarily from Europe, was published recently in the journal *Science*.

Cassini has been in orbit around Saturn since 2004, studying the giant planet, its rings, and its moons. The spacecraft has also sampled millions of ice-rich dust grains with its cosmic dust analyzer instrument. The vast majority of the sampled grains originate from active jets that spray from the surface of Saturn's geologically active moon Enceladus. But among the myriad microscopic grains collected by Cassini, a special few — just 36 grains — stand out from the crowd. Scientists conclude these specks of material came from interstellar space — the space between the stars.

Alien dust in the solar system is not unanticipated. In the 1990s, the ESA/NASA Ulysses mission made the first *in situ* observations of this material, which were later confirmed by NASA's Galileo spacecraft. The dust was traced back to the local interstellar cloud, a nearly empty bubble of gas and dust that our solar system is traveling through with a distinct direction and speed.

"From that discovery, we always hoped we would be able to detect these interstellar interlopers at Saturn with Cassini. We knew that if we looked in the right direction, we should find them," said Nicolas Altobelli, Cassini project scientist at the European Space Agency (ESA) and lead author of the study. "Indeed, on average, we have captured a few of these dust grains per year, traveling at high speed and on a specific path quite different from that of the usual icy grains we collect around Saturn."

The tiny dust grains were speeding through the Saturn system at over 72,000 kilometers per hour (45,000 miles per hour), fast enough to avoid being trapped inside the solar system by the gravity of the Sun and its planets. "We're thrilled Cassini could make this detection, given that our instrument was designed primarily to measure dust from within the Saturn system, as well as all the other demands on the spacecraft," said Marcia Burton, a Cassini fields and particles scientist at NASA's Jet Propulsion Laboratory in Pasadena, California, and a co-author of the paper.

Importantly, unlike Ulysses and Galileo, Cassini was able to analyze the composition of the dust for the first time, showing it to be made of a very specific mixture of minerals, not ice. The grains all had a surprisingly similar chemical makeup, containing major rock-forming elements like magnesium, silicon, iron, and calcium in average cosmic proportions. Conversely, more reactive elements like sulfur and carbon were found to be less abundant compared to their average cosmic abundance. "Cosmic dust is produced when stars die, but with the vast range of types of stars in the universe, we naturally expected to encounter a huge range of dust types over the long period of our study," said Frank Postberg of the University of Heidelberg, a co-author of the paper and co-investigator of Cassini's dust analyzer.

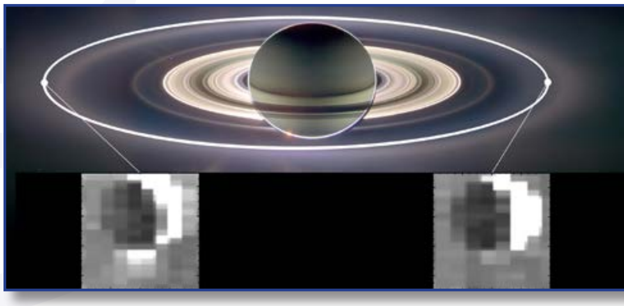
Stardust grains are found in some types of meteorites, which have preserved them since the birth of our solar system. They are generally old, pristine, and diverse in their composition. But surprisingly, the grains detected by Cassini aren't like that. They have apparently been made rather uniform through some repetitive processing in the interstellar medium, the researchers said.

The authors speculate on how this processing of dust might take place: Dust in a star-forming region could be destroyed and recondense multiple times as shock waves from dying stars passed through, resulting in grains like the ones Cassini observed streaming into our solar system. "The long duration of the Cassini mission has enabled us to use it like a micrometeorite observatory, providing us privileged access to the contribution of dust from outside our solar system that could not have been obtained in any other way," said Altobelli.

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

Enceladus Jets: Surprises in Starlight

During a recent stargazing session, NASA's Cassini spacecraft watched a bright star pass behind the plume of gas and dust that spews from Saturn's icy moon Enceladus. At first, the data from that observation had scientists scratching their heads. What they saw didn't fit their predictions. The observation has led to a surprising new clue about the remarkable geologic activity on Enceladus: It appears that at least some of the narrow jets that erupt from the moon's surface blast with increased fury when the moon is farther from Saturn in its orbit. Exactly how or why that's happening is far from clear, but the observation gives theorists new possibilities to ponder about the twists and turns in the "plumbing" under the moon's frozen surface. Scientists are eager for such clues because, beneath its frozen shell of ice, Enceladus is an ocean world that might have the ingredients for life.



This set of images from NASA's Cassini mission shows how the gravitational pull of Saturn affects the amount of spray coming from jets at the active moon Enceladus. Enceladus has the most spray when it is farthest away from Saturn in its orbit (inset image on the left) and the least spray when it is closest to Saturn (inset image on the right). Credit: NASA/JPL-Caltech/University of Arizona/Cornell/SSI.

During its first few years after arriving at Saturn in 2004, Cassini discovered that Enceladus continuously spews a broad plume of gas and dust-sized ice grains from the region around its south pole. This plume extends hundreds of miles into space, and is several times the width of the small moon itself. Scores of narrow jets burst from the surface along great fractures known as "tiger stripes" and contribute to the plume. The activity is understood to originate from the moon's subsurface ocean of salty liquid water, which is venting into space.

Cassini has shown that more than 90% of the material in the plume is water vapor. This gas lofts dust grains into space where sunlight scatters off them, making them visible to the spacecraft's cameras. Cassini has even collected some of the particles being blasted off Enceladus and analyzed their composition. Previous Cassini observations saw the eruptions spraying three times as much icy dust into space when Enceladus neared the farthest point in its elliptical orbit around Saturn. But until now, scientists hadn't had an opportunity to see if the gas part of the eruptions — which makes up the majority of the plume's mass — also increased at this time.

So on March 11, 2016, during a carefully planned observing run, Cassini set its gaze on Epsilon Orionis, the central star in Orion's belt. At the appointed time, Enceladus and its erupting plume glided in front of the star. Cassini's ultraviolet imaging spectrometer (UVIS) measured how water vapor in the plume dimmed the star's ultraviolet light, revealing how much gas the plume contained. Since lots of extra dust appears at this point in the moon's orbit, scientists expected to measure a lot more gas in the plume, pushing the dust into space.

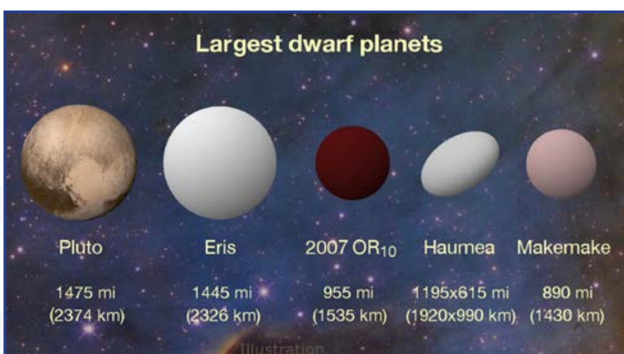
But instead of the expected huge increase in water vapor output, the UVIS instrument only saw a slight bump — just a 20% increase in the total amount of gas. Cassini scientist Candy Hansen quickly set to work trying to figure out what might be going on. Hansen, a UVIS team member at the Planetary Science Institute in Tucson, led the planning of the observation. "We went after the most obvious explanation first, but the data told us we needed to look deeper," she said. As it turned out, looking deeper meant paying attention to what was happening closer to the moon's surface.

Hansen and her colleagues focused their attention on one jet known informally as "Baghdad I." The researchers found that while the amount of gas in the overall plume didn't change much, this particular jet was four times more active than at other times in Enceladus' orbit. Instead of supplying just 2% of the plume's total water vapor, as Cassini previously observed, it was now supplying 8% of the plume's gas.

This insight revealed something subtle, but important, according to Larry Esposito, UVIS team lead at the University of Colorado at Boulder. "We had thought the amount of water vapor in the overall plume, across the whole south polar area, was being strongly affected by tidal forces from Saturn. Instead we find that the small-scale jets are what's changing." This increase in the jets' activity is what causes more icy dust grains to be lofted into space, where Cassini's cameras can see them, explained Esposito.

2007 OR10: Largest Unnamed World in the Solar System

Dwarf planets tend to be a mysterious bunch. With the exception of Ceres, which resides in the main asteroid belt between Mars and Jupiter, all members of this class of minor planets in our solar system lurk in the depths beyond Neptune. They are far from Earth — small and cold — which makes them difficult to observe, even with large telescopes. So it's little wonder that astronomers only discovered most of them in the past decade or so.



New K2 results peg 2007 OR10 as the largest unnamed body in our solar system and the third largest of the current roster of about half a dozen dwarf planets. The dwarf planet Haumea has an oblong shape that is wider on its long axis than 2007 OR10, but its overall volume is smaller. Credits: Konkoly Observatory/András Pál, Hungarian Astronomical Association/Iván Éder, NASA/JHUAPL/SwRI.

Pluto is a prime example of this elusiveness. Before NASA's New Horizons spacecraft visited it in 2015, the largest of the dwarf planets had appeared as little more than a fuzzy blob, even to the keen-eyed Hubble Space Telescope. Given the inherent challenges in trying to observe these far-flung worlds, astronomers often need to combine data from a variety of sources in order to tease out basic details about their properties.

Recently, a group of astronomers did just that by combining data from two space observatories to reveal something surprising: A dwarf planet named 2007 OR10 is significantly larger than previously thought. The results peg 2007 OR10 as the largest unnamed world in our solar system and the third largest of the current roster of about half a dozen dwarf planets. The study also found that the object is quite dark and rotating more slowly than almost any other body orbiting our Sun, taking close to 45 hours to complete its daily spin.

For their research, the scientists used NASA's repurposed planet-hunting Kepler space telescope — its mission now known as K2 — along with the archival data from the infrared Herschel Space Observatory. A paper reporting these results has been published in *The Astronomical Journal*. "K2 has made yet another important contribution in revising the size estimate of 2007 OR10. But what's really powerful is how combining K2 and Herschel data yields such a wealth of information about the object's physical properties," said Geert Barentsen, Kepler/K2 research scientist at NASA's Ames Research Center.

The revised measurement of the planet's diameter, 1535 kilometers (955 miles), is about 100 kilometers (60 miles) greater than the next largest dwarf planet, Makemake, or about one-third smaller than Pluto. Another dwarf planet, named Haumea, has an oblong shape that is wider on its long axis than 2007 OR10, but its overall volume is smaller.

Like its predecessor mission, K2 searches for the change in brightness of distant objects. The tiny, telltale dip in the brightness of a star can be the signature of a planet passing, or transiting, in front. But, closer to home, K2 also looks out into our solar system to observe small bodies such as comets, asteroids, moons, and dwarf planets. Because of its exquisite sensitivity to small changes in brightness, Kepler is an excellent instrument for observing the brightness of distant solar system objects and how that changes as they rotate.

Figuring out the size of small, faint objects far from Earth is tricky business. Since they appear as mere points of light, it can be a challenge to determine whether the light they emit represents a smaller, brighter object, or a larger, darker one. This is what makes it so difficult to observe 2007 OR10 — although its elliptical orbit brings it nearly as close to the Sun as Neptune, it is currently twice as far from the Sun as Pluto.

Enter the dynamic duo of Kepler and Herschel. Previous estimates based on Herschel data alone suggested a diameter of roughly 1280 kilometers (795 miles) for 2007 OR10. However, without a handle on the object's rotation period, those studies were limited in their ability to estimate its overall brightness, and hence its size. The discovery of the very slow rotation by K2 was essential for the team to construct more detailed models that revealed the peculiarities of this dwarf planet. The rotation measurements even included hints of variations in brightness across its surface. Together, the two space telescopes allowed the team to measure the fraction of sunlight reflected by 2007 OR10 (using Kepler) and the fraction absorbed and later radiated back as heat (using Herschel). Putting these two datasets together provided an unambiguous estimation of the dwarf planet's size and how reflective it is.

According to the new measurements, the diameter of 2007 OR10 is some 250 kilometers (155 miles) larger than previously thought. The larger size also implies higher gravity and a very dark surface — the latter because the same amount of light is being reflected by a larger body. This dark nature is different from most dwarf planets, which are much brighter. Previous groundbased observations found 2007 OR10 has a characteristic red color, and other researchers have suggested this might be due to methane ices on its surface. "Our revised larger size for 2007 OR10 makes it increasingly likely the planet is covered in volatile ices of methane, carbon monoxide, and nitrogen, which would be easily lost to space by a smaller object," said András Pál at Konkoly Observatory in Budapest, Hungary, who led the research.

"It's thrilling to tease out details like this about a distant, new world — especially since it has such an exceptionally dark and reddish surface for its size."

As for when 2007 OR10 will finally get a name, that honor belongs to the object's discoverers. Astronomers Meg Schwamb, Mike Brown, and David Rabinowitz spotted it in 2007 as part of a survey to search for distant solar system bodies using the Samuel Oschin Telescope at Palomar Observatory near San Diego. "The names of Pluto-sized bodies each tell a story about the characteristics of their respective objects. In the past, we haven't known enough about 2007 OR10 to give it a name that would do it justice," said Schwamb. "I think we're coming to a point where we can give 2007 OR10 its rightful name."

For more information, visit *http://www.nasa.gov/kepler* and *http://www.nasa.gov/herschel*.

47th Lunar and Planetary Science Conference

March 21–25, 2016
The Woodlands, Texas

The 47th Lunar and Planetary Science Conference (LPSC) was held in March at The Woodlands Waterway Marriott Hotel and Convention Center in The Woodlands, Texas. Abstract submission numbers were up, with 2074 abstracts being submitted from 43 countries. Attendance was high as well, with 1720 attendees from 32 countries. LPSC is obviously a meeting that is both accessible and important to young scientists, as reflected by the fact that student participation made up more than 30% of the overall number of participants.

LPSC, co-chaired by Stephen Mackwell of the Lunar and Planetary Institute and Eileen Stansberry of the NASA Johnson Space Center, began with the usual Sunday evening registration and welcome event. The welcome event was held in the Waterway Ballrooms, giving participants an opportunity to meet and greet more of their friends and colleagues. Many participants have said that one of the appealing qualities of the meeting is that it feels as much like a homecoming or reunion event as a scientific conference, and this was in evidence on Sunday night from the smiles, hugs, and earnest conversations held among attendees.

Jim Green of NASA's Planetary Science Division addressed the planetary science community during the Monday evening NASA Headquarters Briefing.

On Monday morning, the oral sessions began. The conference featured four-and-a-half days of sessions, featuring such topics as impacts; planetary dynamics/tectonics, differentiation, atmospheres, aeolian processes, fluvial processes, polar processes and/or cryospheres, and volcanism and igneous processes; early solar system chronology; small bodies; outer planets/satellites/rings; differentiated meteorites and bodies; chondrites and their components; martian geomorphology, geochemistry, and petrology; the Moon, Venus, and Mercury; and much, much more. Special sessions included NASA's Planetary Science Division Facilities, New Horizons at Pluto; and Ceres Unveiled: What We Have Learned from Dawn. The complete program and abstracts are available at *http://www.hou.usra.edu/meetings/lpsc2016*.

Dr. Alan Stern, Principal Investigator for the New Horizons mission, presented this year's Masursky Lecture.

The plenary session on Monday afternoon featured the Masursky Lecture, "New Horizons: The Exploration of the Pluto System and the Kuiper Belt Beyond," by Dr. Alan Stern of the Southwest Research Institute in Boulder, Colorado. The winners of the 2015 Dwornik Awards and 2016 LPI Career Development Awards were also recognized. During the Monday evening NASA Headquarters Briefing, representatives from the Planetary Sciences Division of NASA's Science Mission Directorate addressed meeting attendees.

So many posters...

Poster sessions held on Tuesday and Thursday evening included the same topics covered in the oral sessions, as well as topics such as education and public outreach, material and environmental analogs, planetary mission concepts, and instrument and payload concepts. A number of exhibitors were also on hand, featuring everything from virtual reality demonstrations to the latest planetary science publications and information about student opportunities in planetary science.

Tuesday evening also featured a public lecture given by Stern entitled "The Exploration of Pluto." Topics covered included the history of the New Horizons mission, the science behind it, the capabilities of the instrument payload, the encounter with dwarf planet Pluto, and the major scientific discoveries made to date. Also briefly outlined was the proposed New Horizons extended mission to fly across the Kuiper belt, exploring further into space.

In addition to the oral sessions, there were many peripheral meetings and activities held during the week, including a workshop on potential Mars returned sample science, a professional development workshop for educators, a community forum on the restoration and synthesis of planetary geochemical data, a discussion group about ways to advance research in low-Earth orbit, updates from various mission teams and analysis groups, a networking meeting for young faculty in the planetary sciences, an information meeting for those interested in the NASA Postdoctoral Program, and much, much more.

For the fourth year in a row, the conference utilized LPSC Microbloggers to use social media to provide real-time coverage of the science presented during the sessions. Combined with a Twitter feed on the meeting website, this coverage not only allowed participants to know what was going on in the sessions they were unable to attend, but also provided information for those in other parts of the world who were not able to make it to the meeting. The popularity of the constant Twitter feeds was evidenced by the fact that the hashtag #LPSC2016 was frequently trending on Twitter throughout the meeting. This was also the fourth year that the conference allowed poster presenters to submit e-posters, which not only gave more visibility to the work of those authors who chose to submit them, but provided yet another way for non-attendees to have more access to the science presented at the meeting.

47th LPSC Microbloggers.

Plans are already underway for the 48th LPSC, which is scheduled for March 20–24, 2017. Mark your calendars! Details will be made available on the meeting website at *http://www.hou.usra.edu/meetings/lpsc2017*.

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

Upcoming Public Event Opportunities

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

- Resources for evening observing session events include the Lunar and Planetary Institute's Look Up guides at *http://www.lpi.usra.edu/education/look_up/*.
- NASA's Solar System Ambassadors (*http://solarsystem.nasa.gov/ssa/directory.cfm*) can volunteer to assist with your events

- To find out about existing events you can assist with, check out the NASA Museum Alliance events at *http://informal.jpl.nasa.gov/museum/Visit*.

Juno Arrives at Jupiter —

The Juno mission will improve our understanding of the solar system's beginnings by revealing the origin and evolution of Jupiter. It is scheduled to begin orbiting Jupiter around July 4, 2016. A toolkit of resources for your events is available at *http://solarsystem.nasa.gov/planets/jupiter/junotooklit*.

OSIRIS-REx Launches —

NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission will travel to near-Earth asteroid Bennu and bring a small sample back to Earth for study. OSIRIS-REx is scheduled to launch in September 2016. Audiences are invited to participate in Target Asteroids! (*http://www.asteroidmission.org/get-involved/target-asteroids/*), a citizen science project that contributes to our understanding of near-Earth asteroids.

Total Eclipse of the Sun —

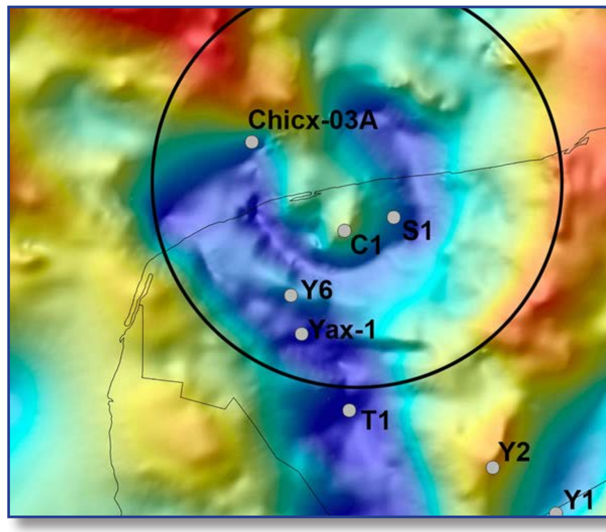
http://sunearthday.nasa.gov/discoveries/science/2017-eclipse.php

On August 21, 2017, there will be a total eclipse of the Sun visible from the U.S. The path of the total eclipse is only about 97 kilometers (60 miles) wide and goes from a beach in Oregon to a beach in South Carolina. The National Science Teachers Association (NSTA) is making available a popular-level introduction to help explain the eclipse, and how to view it, to students and the public: *http://www.nsta.org/publications/press/extras/files/solarscience/SolarScienceInsert.pdf*.

American Astronomical Society Education Prize

The American Astronomical Society (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 2016 must arrive in the Secretary's office by June 30. Information about submitting a nomination is available at *http://aas.org/grants-and-prizes/prize-nominations*.

LPI Announces New Chicxulub Educational Website



Twenty-five years after the discovery of the Chicxulub crater was announced at the Lunar and Planetary Science Conference (LPSC), one of the principals of that work, David Kring of the Lunar and Planetary Institute (LPI), is releasing five dozen illustrations that faculty and students can use for educational purposes.

The illustrations will support classroom discussions of the (1) Cretaceous-Tertiary (K-T) boundary, (2) Chicxulub crater, (3) Chicxulub environmental effects, and (4) Chicxulub drilling. The products are available in the LPI's Classroom Illustrations library at *http://www.lpi.usra.edu/exploration/training/resources/?view=illustrations*.

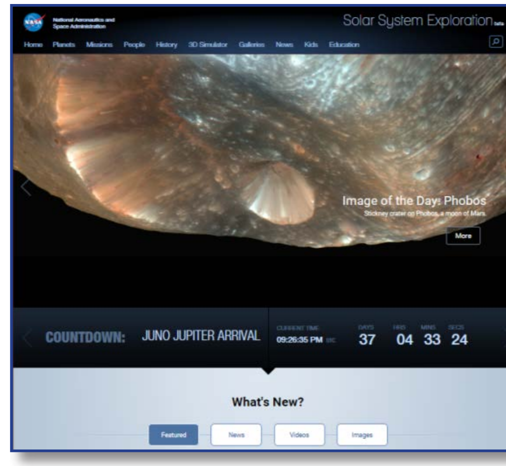
The LPI has also used those images to update its Chicxulub and K-T boundary educational website: *http://www.lpi.usra.edu/science/kring/epo_web/impact_cratering/Chicxulub*.

Conduct Education and Public Engagement at AGU

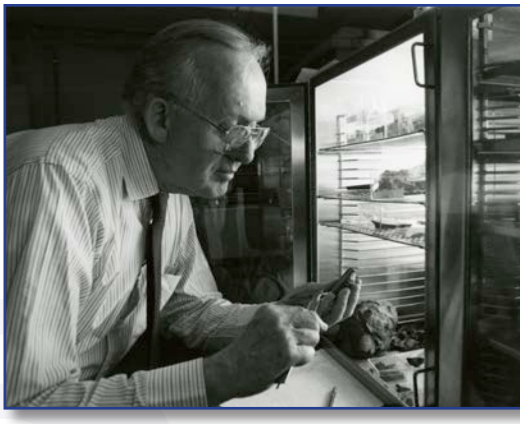
Exploration Station is an annual event that takes place at the American Geophysical Union (AGU) Fall Meeting, providing a venue for the local community and AGU members to come together to share the excitement of science. Participants meet scientists, do hands-on science, and take home fun resources. To present at Exploration Station, please read the FAQ at *http://education.agu.org/files/2016/05/Exhibitor-FAQ-1-1.pdf* and e-mail *exploration-station@agu.org* to register. All costs for the event other than shipping and handling of materials are covered by AGU.

AGU is also accepting proposals from teams of at least one scientist and one education specialist to present during the Geophysical Information for Teachers (GIFT) Workshop at the AGU Fall Meeting. This workshop enables scientists to work closely with an education specialist to develop and share material with K–12 teachers and informal educators. Each team of presenters will receive one free full-week registration for the AGU Fall Meeting (in addition to the free registration for all K–12 educators). Applications are due no later than August 31, 2016; visit *http://serc.carleton.edu/nesta/gift.html*.

Solar System Exploration Website



This frequently updated site strives to be a real-time, living encyclopedia of robotic exploration of our solar system; to provide the public, students, and teachers with reliable, accurate, up-to-date planet and mission information; and to create a complete historical record of deep space exploration. To check out the site, visit *http://solarsystem.nasa.gov*.



Roy S. Clarke Jr., 1925–2016

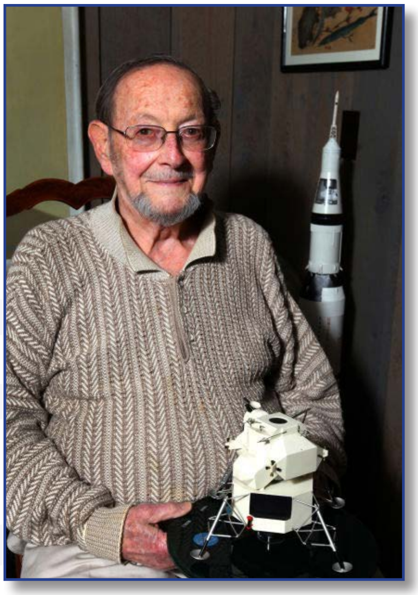
Roy S. Clarke Jr., Emeritus Curator in the Department of Mineral Sciences at the Smithsonian Institution in Washington, DC, passed away on April 1, 2016, at the age of 91. Born January 23, 1925, Clarke followed distinguished service in the Army during World War II with studies at Cornell University, earning his B.A. in 1949. Early in his career, he was employed at the U.S. Geological Survey as an analytical chemist, while earning an M.S. at George Washington University in 1957. In October 1957 he transferred to the Smithsonian, where he would remain through his retirement in December 1993 and as an Emeritus Curator following retirement.

Clarke began his career as an analytical chemist only three weeks before the Soviet Union launched Sputnik, the first Earth-orbiting satellite and the event that marked the start of the space race. Although his interests were initially confined to the chemical analysis of minerals, Clarke was soon encouraged to focus more on the meteorites in the national collection. His research interests centered on understanding the origin of iron meteorites, particularly coarse-structured irons rich in phosphorus. Upon the retirement of Ed Henderson in 1965, Clarke assumed the role of Curator-in-Charge of the U.S. National Meteorite Collection.

Clarke became an active member of the Meteoritical Society, serving as Secretary of the Society from 1967 to 1970. He played a pivotal role in the acquisition of the Allende meteorite in 1969, traveling to Mexico to acquire thousands of individual stones. He returned to school for his Ph.D. later in life, studying at George Washington University, where he graduated in 1976. At almost the same time as earning his Ph.D., Clarke was involved in the contentious legal acquisition of the Old Woman meteorite, which would become the largest single meteorite in the Smithsonian's collection and, coincidentally, was a coarse-structured iron meteorite rich in phosphorus.

Clarke also played a pivotal role in the formation and management of the U.S. Antarctic Meteorite Program, a cooperation between the Smithsonian, NASA, and the National Science Foundation. Upon retirement, Clarke's interests turned to the history of meteoritics and the history of The Meteoritical Society. This led to a series of papers about meteoritics at the Smithsonian, among other topics. Clarke did an outstanding job of growing the U.S. national collection of meteorites, and provided countless outside investigators with material for their study. In 2014, he was awarded The Meteoritical Society's Service Award.

— Text courtesy of The Meteoritical Society



Gerald J. Wasserburg, 1927–2016

Gerald J. Wasserburg was an American geologist. At the time of his death, he was the John D. MacArthur Professor of Geology and Geophysics, Emeritus, at the California Institute of Technology. He was best known for his work in the fields of isotope geochemistry, cosmochemistry, meteoritics, and astrophysics.

After leaving the U.S. Army, where he received the Combat Infantryman Badge, he attended college on the G.I. Bill. Wasserburg completed his Ph.D. from the University of Chicago in 1954, with a thesis on the development of potassium-argon dating. He joined the faculty at the California Institute of Technology (Caltech) in 1955 as Assistant Professor. He became Associate Professor in 1959 and Professor of Geology and Geophysics in 1962, and in 1982, became the John D. MacArthur Professor of Geology and Geophysics, retiring in 2001. Along with Typhoon Lee and Dimitri Papanastassiou, he discovered the presence of short-lived radioactive aluminum-26 in the early solar system and short-lived palladium-107.

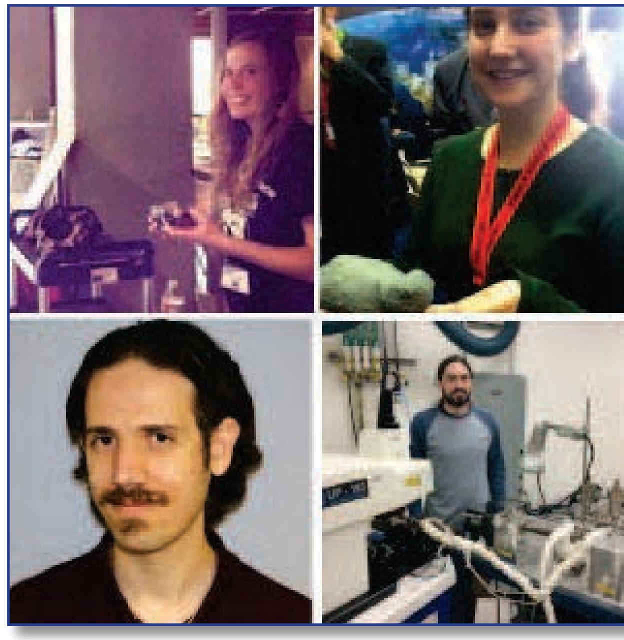
Wasserburg was deeply involved in the Apollo program with the returned lunar samples, and was the last living member of the so-called “Four Horsemen,” whose other members were Bob Walker, Jim Arnold, and Paul Gast. He pioneered the precise measurement of ultra-small samples under strict clean room conditions with minimal contamination. He was also the co-inventor of the Lunatic Spectrometer (the first fully digital, mass spectrometer with computer controlled magnetic field scanning and rapid switching) and founder of the “Lunatic Asylum” research laboratory at Caltech, which specialized in high-precision, high-sensitivity isotopic analyses of meteorites and lunar samples. He and his co-workers were major contributors to establishing a chronology for the Moon and proposed the hypothesis of the late heavy bombardment (LHB) of the whole inner solar system.

Wasserburg’s research led to a better understanding of the origins and history of the solar system and its component bodies and the precursor stellar sources contributing to the solar system. This research established a timescale for the development of the early solar system, including the processes of nucleosynthesis and the formation and evolution of the planets, the Moon, and the meteorites.

Wasserburg was a member of the U.S. National Academy of Science, the American Philosophical Society, the American Academy of Arts and Sciences, and the Norwegian Academy of Science and Letters. He was also the recipient of numerous awards, including the Arthur L. Day Medal in 1970, the NASA Distinguished Public Service Medal in 1972 and 1978, the Wollaston Medal in 1985, the Gold Medal of the Royal Astronomical Society in 1991, the Bowie Medal in 2008, the H. Hess Medal of the American Geophysical Union in 1985, the Leonard Medal of the Meteoritical Society in 1975, the J. Lawrence Smith Medal of the National Academy of Science in 1985, the Holmes Medal of the European Union of Geosciences in 1986, and the V. M. Goldschmidt Medal of the Geochemical Society in 1978.

Inaugural Nininger Student Travel Award Winners Announced

The Center for Meteorite Studies and the School of Earth and Space Exploration (SESE) of Arizona State University are pleased to announce the winners of the inaugural Nininger Student Travel Award. The goal of this award is to support travel to the annual Lunar and Planetary Science Conference (LPSC) of up to four SESE undergraduate and graduate students to present their latest results.



Clockwise from top left: Emilie Dunham, Jessica Noviello, Ehsan Gharib-Nezhad, and Cameron Mercer. Credit: Arizona State University.

The awardees are:

Emilie Dunham: *"Further Evidence of Beryllium-10 Heterogeneity in the Early Solar System Inferred from Be-B Systematics of Refractory Inclusions in A Minimally Altered CR2 Chondrite"*

Dunham is currently in the second year of her Ph.D., studying in the Center for Meteorite Studies under Professor Meenakshi Wadhwa. Her research focuses on determining the chemical and isotopic composition of meteorite components, to better understand the astrophysical birthplace of our solar system.

Ehsan Gharib-Nezhad: *"Simulating Haze Particles in a H_2-Rich Exoplanet Atmosphere with High Temperature Discharge Experiments"*

Gharib-Nezhad received his M.S. in physical chemistry from the University of Tehran at Iran in 2013. His thesis focused on the spectroscopy of diatomic molecules of astrophysical interest. Upon completion of his master's degree, his enthusiasm for astrochemistry lead him to apply to ASU, where he is currently working toward his Ph.D. under the supervision of Professor James Lyons in the School of Earth and Space Exploration.

Cameron Mercer: *"Exploring Non-Uniform $^{40}Ar^*$ Loss in Apollo 16 Impact Melt Breccias Using a Laser Microprobe"*

At LPSC, Mercer presented 139 new spot fusion argon-40/argon-39 dates for three samples from the Apollo 16 sample archive. Combined with ongoing work, the laser microprobe argon-40/argon-39 data will help to constrain the thermal histories recorded by these samples. Mercer is a Ph.D. candidate studying under Professor Kip Hodges.

Jessica Noviello: *"Order from Chaos: A Quantitative Approach to Identifying Small Chaos Features on Europa"*

Noviello is a second-year Ph.D. student studying under Professor Alyssa Rhoden. Her LPSC presentation explored the color data taken of Europa during the Galileo mission, in order to classify small chaos patches. Combining the color data with other observational characteristics could enable the identification of small patches of chaos in low-resolution images of Europa, yielding more data on the global frequency of chaos patches, which will help constrain heat-flux models of chaos model formation and make testable predictions for the upcoming Europa Flyby Flagship mission.

Congratulations to these students!

Kasting Receives the 2016 NAS Award in Early Earth and Life Sciences

James F. Kasting, Evan Pugh University Professor of Geosciences at Pennsylvania State University, received the 2016 National Academy of Sciences (NAS) Award in Early Earth and Life Sciences, presented with the Stanley Miller Medal. The composition of a planet's atmosphere affects the climate on the planet's surface. A thick layer of carbon dioxide, for instance, drives the temperature on Venus to a whopping 467°C (873°F). On Earth, in contrast, the atmosphere is dominated by nitrogen, but there is enough carbon dioxide and other greenhouse gases to keep the surface warm enough for life. In the past, though, Earth's atmosphere has been very different, with levels of oxygen and carbon dioxide fluctuating over time.

Kasting has made fundamental insights into this atmospheric evolution through the development of numerical models. The core of his research has been the greenhouse gas carbon dioxide. He has calculated the minimum levels of carbon dioxide needed to prevent the planet from freezing into a "Snowball Earth" scenario, for instance. And he and his colleagues have used his models to determine when the planet's carbon dioxide will run out and its water will be lost, calculating that Earth will no longer be able to support life in another 2 billion years or less. Kasting's studies into the evolution of carbon dioxide and other atmospheric gases — such as oxygen, methane, and nitrous oxide — have provided insight into the proliferation of life on the early Earth. He has also made major contributions in the search for life on other planets, including refining the concept of the "habitable zone" — the region around a star where a planet can support liquid water and possibly life.

The NAS Award in Early Earth and Life Sciences was established by the NAS Council in October 2008 by combining two awards: the Charles Doolittle Walcott Medal, established by a gift of Mrs. Mary Vaux

Walcott in memory of her husband, Charles Doolittle Walcott, and the Stanley Miller Medal, established through a bequest from NAS member Stanley Miller. The award rotates presentation between the Charles Doolittle Walcott Medal for research on Cambrian or pre-Cambrian life, and the Stanley Miller Medal, which recognizes research on Earth's early development as a planet, including prebiotic chemistry and the origin of life; planetary accretion, differentiation, and tectonics; and early evolution of the atmosphere and oceans. Each medal is presented with a $10,000 prize.

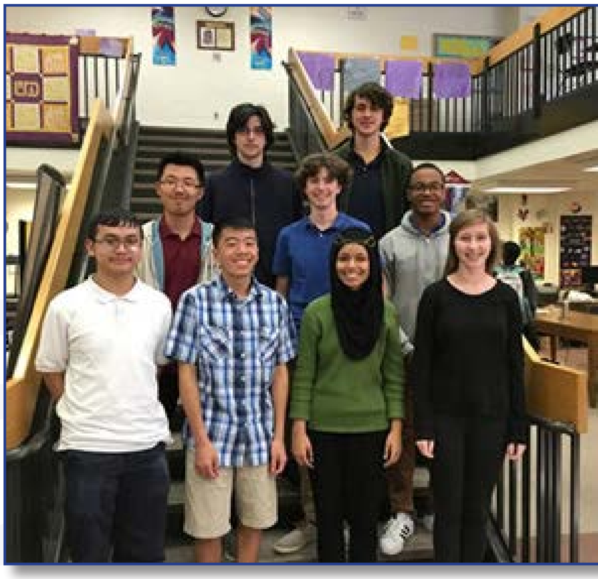
Center for Lunar Science and Exploration Announces 2016 Intern Class

The Center for Lunar Science and Exploration of the Lunar and Planetary Institute (LPI) and NASA Johnson Space Center is pleased to announce the 2016 class of Exploration Science Summer Interns. The internship program provides students with an opportunity to be involved in exploration science activities, thus effectively training a new generation of space exploration leaders. This summer, students will be involved in activities that support missions to both the Moon and near-Earth asteroids. Working as a team, students make assessments and traverse plans for a particular destination (e.g., on the lunar farside) or a more general assessment of a class of possible exploration targets (e.g., small near-Earth asteroids). It is a unique opportunity to integrate scientific input with exploration activities in a way that mission architects and spacecraft engineers can use.

The 10-week program runs May 23 through July 29, 2016. Applications were accepted from graduate students in geology, planetary science, and related programs. The Exploration Science Summer Intern Program is supported with funding from the LPI and the Solar System Exploration Research Virtual Institute at NASA Ames Research Center.

Congratulations to the nine students chosen to participate in this summer's program: Elyse Allender (University of Cincinnati), Natasha Almeida (Birkbeck College London), John Cook (University of Houston), Jessica Ende (University of Tennessee), Oscar Kamps (Utrecht University), Sara Mazrouei-Seidani (University of Toronto), Csilla Orgel (Freie Universität Berlin), Thomas Slezak (Brigham Young University), and Assi-Johanna Soini (University of Helsinki).

For more information about the program, visit *http://www.lpi.usra.edu/exploration_intern/*.



Upper Darby High School Receives Top Honor for Lunar Research Project

The Center for Lunar Science and Exploration (CLSE), a joint effort between the Lunar and Planetary Institute (operated by the Universities Space Research Association for NASA) and NASA's Johnson Space Center, awarded the top honor to a team of high school students from Upper Darby High School in Drexel Hill, Pennsylvania, in the national research competition for the Exploration of the Moon and Asteroids by Secondary Students (ExMASS) program.

Selected by a panel of planetary scientists, the team's project results determined the thickness of lava flows (basalt) that filled a large impact basin on the lunar surface beneath the Apollo 11 landing site. "Upper Darby High School's success in the ExMASS program accentuates the ability of high school students to conduct scientific research when given the opportunity," says Andy Shaner, Education Lead for the CLSE. "No matter the outcome of their research, participation in this program builds students' confidence in pursuing a STEM career."

Forty-three students from 10 high schools across the country participated in the ExMASS program managed by the CLSE, a member of the NASA Solar System Exploration Research Virtual Institute (SSERVI). Student teams, paired with a scientist advisor, embarked on authentic, data-rich, scientific research experiences of the Moon and asteroids that cover the breadth of NASA SSERVI science and exploration goals, and CLSE research priorities.

The Upper Darby High School students will present their research project, "Basalt Thickness of Mare Tranquillitatis Using Two Methods," at the NASA Exploration Science Forum, to be held at NASA's Ames Research Center in July of this year. The winning team includes Chris DeMott, Galen Farmer, Daniel Gordon, Isabel Hunt, Kenneth Lin, Thomas Nguyen, Zach Thornton, Vince Tran, and Most Yeasmin and their teachers, Roseann Burns and Joshua Taffel. The team's advisor was Dr. Amanda Nahm, German Aerospace Center [Deutsches Zentrum für Luft- und Raumfahrt e.V (DLR)].

ExMASS builds on its predecessor, the highly successful CLSE High School Lunar Research Projects program, which ran from 2009 to 2013 and involved approximately 240 students throughout the United States. For more information about the program, visit *http://www.lpi.usra.edu/exploration/education/hsResearch/*.

Orlando Figueroa to Receive the National Space Society's 2016 Space Pioneer Award for Non-Legislative Government Service

The National Space Society (NSS) has announced that Orlando Figueroa is the winner of the 2016 Space Pioneer Award for Non-Legislative Government Service. This award recognizes the work Figueroa has done at NASA Goddard Space Flight Center and NASA Headquarters, including serving as the NASA Deputy Chief Engineer, Director for Mars Exploration, and other important positions at Goddard in engineering, in management, and as a Deputy Center Director for Science and Technology.

"It is an honor to be recognized for whatever contribution I and the NASA teams I was privileged to lead made to the exploration of space and to science, and to be able to enjoy as much," said Figueroa. He accepted the award on May 19 at the 2016 International Space Development Conference, which was held in San Juan, Puerto Rico.

After starting work at the Goddard Space Flight Center in 1978, Figueroa served as manager and director of a very wide variety of programs and organizations at NASA Goddard and at NASA Headquarters. His work on cryogenics may assist future development for storage and the transfer in space of such liquids as rocket propellants. Cryogenic storage and transfer technology is an enabler for reusable in-space vehicles and routine space operations.

NSS especially appreciates his many accomplishments during his years as Director for Mars Exploration. After the double failures of the 1998–1999 Mars missions, just five years later Figueroa led NASA's achievement of the double successes of the Mars Exploration Rovers Spirit and Opportunity, which were dramatic comebacks for NASA and the planetary science program.

NASA Welcomes New Director for Its Jet Propulsion Laboratory

The following is a statement from NASA Administrator Charles Bolden on the selection of Michael Watkins as the new director of the agency's Jet Propulsion Laboratory (JPL) in Pasadena, California.

"President Thomas Rosenbaum and his leadership team at the California Institute of Technology (Caltech) have made an outstanding choice in naming Dr. Michael M. Watkins as the new director of JPL. I, for one, cannot wait to work with him to advance our Journey to Mars, along with our understanding of our own planet, our universe, and humanity's place in it.

"Dr. Watkins is no stranger to the NASA family. In more than two decades at JPL, Dr. Watkins played a major role in the Mars Curiosity Rover, Cassini, Mars Odyssey, GRACE, GRAIL, and the GRACE Follow-on missions — to name just a few. I am confident that he will do an excellent job as he begins a new chapter in the incredible legacy that Caltech and NASA have written together through JPL for generations.

"Dr. Watkins will have some very big shoes to fill in succeeding retiring JPL Director Charles Elachi. When American astronauts reach Mars in the 2030s it will be in large part because of the work that Dr. Elachi and his JPL team have done in tandem with NASA colleagues, collaborators and contractors throughout the nation, and indeed our world."

John Grunsfeld Announces Retirement from NASA

Dr. John Grunsfeld announced his retirement from NASA effective April 30, capping nearly four decades of science and exploration with the agency. His tenure includes serving as astronaut, chief scientist, and head of NASA's Earth and space science activities. Grunsfeld has directed NASA's Science Mission Directorate as associate administrator since 2012, managing more than 100 science missions — many of which have produced groundbreaking science, findings and discoveries.

"John leaves an extraordinary legacy of success that will forever remain a part of our nation's historic science and exploration achievements," said NASA Administrator Charles Bolden. "Widely known as the 'Hubble Repairman,' it was an honor to serve with him in the astronaut corps and watch him lead NASA's science portfolio during a time of remarkable discovery. These are discoveries that have rewritten science textbooks and inspired the next generation of space explorers." Geoff Yoder, currently the directorate's deputy, will serve as acting associate administrator until a successor is named.

Notable science achievements under Grunsfeld's leadership include the Curiosity rover Mars landing in 2012 — and its remarkable discoveries about the habitability of ancient Mars — and the July 2015 New Horizons Pluto flyby, completing the initial reconnaissance of the solar system. Grunsfeld also managed numerous missions to protect and study our home planet, including the Deep Space Climate Observatory, Orbiting Carbon Observatory-2, and Global Precipitation Measurement spacecraft, in addition to numerous Earth science aircraft campaigns. These and other projects have laid the foundation for future missions to better understand how Earth is changing. Grunsfeld has also been a strong advocate for research with suborbital rockets, high-altitude balloon flights, and CubeSats, to enable great science and train the next generation of explorers.

"After exploring strange new worlds and seeking out new life in the universe, I can now boldly go where I've rarely gone before — home," said Grunsfeld. "I'm grateful to have had this extraordinary opportunity to lead NASA science, and know that the agency is well-positioned to make the next giant leaps in exploration and discovery."

Preparations are well underway for a host of other missions and activities that will continue Grunsfeld's work. These include the first U.S. mission to return a sample of an asteroid, the first mission to look for signs of life on Jupiter's moon Europa, a mission to study the Sun closer than ever before, participating in a national space weather strategy, and constructing the next rover to Mars, scheduled to launch in 2020.

Universe2Go Introduces the Personal Planetarium Sky Viewer for Your Smart Phone

The digital world collides with the celestial one with the Universe2Go viewfinder, a two-piece augmented reality system for your smart phone that turns any location into a personal planetarium.

The interactive Universe2Go viewfinder uses a smart phone and an accompanying app (both iOS and Android versions available) to create a digital picture of the night sky. Simultaneously, using GPS and modern smart phone sensors, the user can see the night sky through the transparent front of the viewer, superimposing this digital picture over the real starry sky and creating a complete picture, regardless of lighting or weather conditions.

Universe2Go also comes with a comprehensive audio guide to explain exactly what the user is seeing, including all 88 constellations, planets, interstellar space, galaxies, star clusters, and nebulae. Users can choose the subject of those audio explanations, from science to Greek mythology, to appeal to both the casual stargazer and hard-core hobbyist alike.

The Universe2Go viewfinder is easy to use and therefore suitable for users of all ages. Once the smart phone is in place, users tip their heads up, down, to the left, or to the right to navigate the menu. Even the audio guide, which has several hours of explanations and stories, can be controlled by head movements.

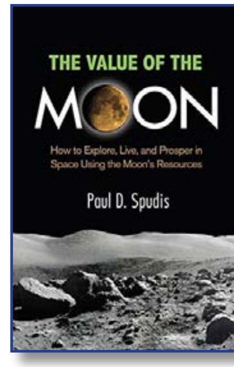
For more information, visit *http://universe2go.com/en*.

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

BOOKS

The Value of the Moon: How to Explore, Live, and Prosper in Space Using the Moon's Resources.

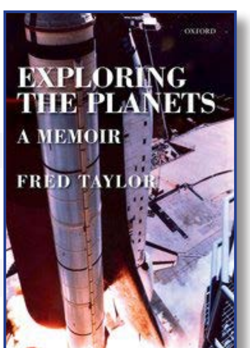
By Paul Spudis. Smithsonian Books. 2016, 272 pp., Hardcover, $27.95.
smithsonianbooks.com



While the Moon was once thought to hold the key to space exploration, in recent decades, the U.S. has largely turned its sights toward Mars and other celestial bodies instead. In *The Value of the Moon*, lunar scientist Spudis argues that the U.S. can and should return to the Moon in order to remain a world leader in space utilization and development and a participant in and beneficiary of a new lunar economy. Spudis explores three reasons for returning to the Moon: It is close, it is interesting, and it is useful. The proximity of the Moon not only allows for frequent launches, but also control of any machinery we place there. It is interesting because recorded deep on its surface and in its craters is the preserved history of the Moon, the Sun, and indeed the entire galaxy. And finally, the Moon is useful because it is rich with materials and energy. The Moon, Spudis argues, is a logical base for further space exploration and even a possible future home for us all. Throughout his work, Spudis incorporates details about man's fascination with the Moon and its place in our shared history. He also explores its religious, cultural, and scientific resonance and assesses its role in the future of spaceflight and our national security and prosperity.

Exploring the Planets: A Memoir.

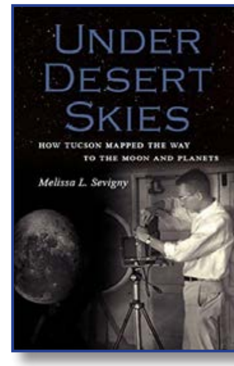
By Fred Taylor. Oxford University Press. 2016, 384 pp., Hardcover, $44.95. *global.oup.com*



The planets fascinate us, and naturally we care about our own Earth, and things like how well we can forecast the weather and whether climate is really changing. *Exploring the Planets* offers a personal account of how the space program evolved. It begins in the era of the first blurry views of our Earth as seen from space, and ends with current plans for sophisticated robots on places as near as our neighbors Venus and Mars and as far away as the rainy lakelands of Saturn's planet-sized moon Titan. The Space Age is now about 50 years old, and for those lucky enough to have been part of it at its inception, it's filled a lifetime. Today, several satellites around Earth have studied the atmosphere and the climate using instruments onboard that the author helped design and build. "Deep space" missions were embarked upon to visit the planets: All the major bodies (six planets, the Moon and minor bodies, asteroids and comets) of the classical solar system have been scrutinized close-up by experiments built in various laboratories worldwide. Most of the narrative is based on the author's experiences at the world's space agencies, research laboratories, and conferences, and at other places as diverse as Cape Canaveral and No. 10 Downing Street.

Under Desert Skies: How Tucson Mapped the Way to the Moon and Planets.

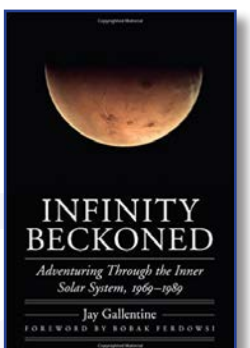
By Melissa Lamberton Sevigny. University of Arizona Press, 2016, 184 pp., Paperback, $19.95.
www.uapress.arizona.edu



President Kennedy's announcement that an American would walk on the Moon before the end of the 1960s took the scientific world by surprise. The study of the Moon and planets had long fallen out of favor with astronomers: They were the stuff of science fiction, not science. An upstart planetary laboratory in Tucson would play a vital role in the nation's grand new venture, and in doing so, it would help create the field of planetary science. Founded by Gerard P. Kuiper in 1960, the Lunar and Planetary Laboratory (LPL) at the University of Arizona broke free from traditional astronomical techniques to embrace a wide range of disciplines necessary to the study of planets, including geology, atmospheric sciences, and the elegant emerging technology of spacecraft. Brash, optimistic young students crafted a unique sense of camaraderie in the fledgling institution. Driven by curiosity and imagination, LPL scientists lived through — and, indeed, made happen — the shattering transition in which Earth's nearest neighbors became more than simple points of light in the sky. *Under Desert Skies* tells the story of how a small corner of Arizona became Earth's ambassador to space. From early efforts to reach the Moon to the first glimpses of Mars' bleak horizons and Titan's swirling atmosphere to the latest ambitious plans to touch an asteroid, LPL's history encompasses humanity's unfolding knowledge about our place in the universe.

Infinity Beckoned: Adventuring Through the Inner Solar System, 1969–1989.

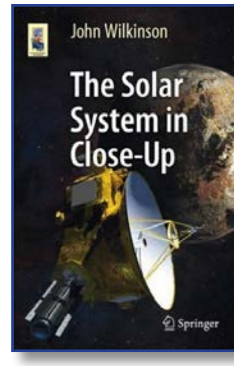
By Jay Gallentine. University of Nebraska Press, 2016, 496 pp., Hardcover, $36.95. *www.nebraskapress.unl.edu*



Infinity Beckoned illuminates a critical period of space history when humans dared an expansive leap into the inner solar system. With an irreverent and engaging style, Gallentine conveys the trials and triumphs of the people on the ground that conceived and engineered the missions that put robotic spacecraft on the heavenly bodies nearest our own. These dedicated space pioneers include such individuals as Soviet Russia's director of planetary missions, who hated his job but kept at it for 15 years, enduring a paranoid bureaucracy where even the copy machines were strictly regulated. Based on numerous interviews, Gallentine delivers a rich variety of stories involving the men and women, American and Russian, responsible for such groundbreaking endeavors as the Mars Viking missions of the 1970s and the Soviet Venera flights to Venus in the 1980s. From the dreamers responsible for the Venus landing who discovered that dropping down through heavy clouds of sulfuric acid and 900° heat was best accomplished by *surfing*, to the five-man teams puppeteering the Soviet Moon rovers from a top-secret, off-the-map town without a name, the people who come to life in these pages persevered in often trying, thankless circumstances. Their legacy is our better understanding of our own planet and our place in the cosmos.

The Solar System in Close Up.

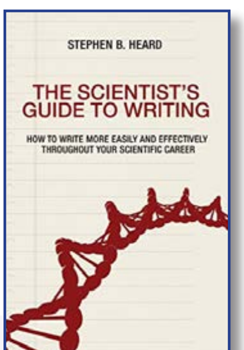
By John Wilkinson. Springer. 2016, 287 pp., Paperback. $34.99. *www.springer.com*



In response to the new information gained about the solar system from recent space probes and space telescopes, experienced science author Wilkinson presents state-of-the art knowledge of the Sun, solar system planets, and small solar system objects like comets and asteroids. He also describes space missions such as the New Horizons space probe, which provided never before seen pictures of the Pluto system; the Dawn space probe, having just visited the asteroid Vesta and the dwarf planet Ceres; and the Rosetta probe in orbit around Comet 67P/Churyumov-Gerasimenko, which has provided extraordinary and exciting pictures. Those and a number of other probes are also changing our understanding of the solar system and providing a wealth of new close-up photos. This book covers all these missions and discusses observed surface features of planets and moons such as their compositions, geysers, aurorae, lightning phenomena, etc. Presenting the fascinating aspects of solar system astronomy, this book is a complete guide to the solar system for amateur astronomers, students, science educators, and interested members of the public.

The Scientist's Guide to Writing: How to Write More Easily and Effectively Throughout Your Scientific Career.

By Stephen B. Heard. Princeton University Press, 2016, 320 pp., Hardcover, $59.95. *global.oup.com*



The ability to write clearly is critical to any scientific career. *The Scientist's Guide to Writing* provides practical advice to help scientists become more effective writers so that their ideas have the greatest possible impact. Drawing on his own experience as a scientist, graduate adviser, and editor, the author emphasizes that the goal of all scientific writing should be absolute clarity; that good writing takes deliberate practice; and that what many scientists need are not long lists of prescriptive rules, but rather direct engagement with their behaviors and attitudes when they write. He combines advice on such topics as how to generate and maintain writing momentum with practical tips on structuring a scientific paper, revising a first draft, handling citations, responding to peer reviews, managing co-authorships, and more. In an accessible, informal tone, this book explains essential techniques that students, postdoctoral researchers, and early career scientists need to write more clearly, efficiently, and easily. It emphasizes writing as a process, not just a product; encourages habits that improve motivation and productivity; explains the structure of the scientific paper and the function of each part; provides detailed guidance on submission, review, revision, and publication; and addresses issues related to co-authorship, English as a second language, and more.

GLOBE

Lunar Wonder Globe.

Produced by Replogle Globes, $10.00. *www.replogleglobes.com*

The Lunar Wonder Globe, with a diameter of 4.3 inches (10.9 centimeters), offers exceptionally smooth rotation on two different axes. Identify lunar surface features such as craters, seas, rilles, valleys, and mountain ranges, and even spot sites of manned and unmanned Moon landings. Exceptional map details make this an instructive and fascinating globe for all ages.

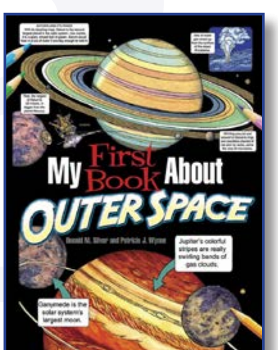
FOR KIDS!!!

Eye Wonder: Space.

By Carole Stott. DK Publishing, 2016, 56 pp., Hardcover. $10.99. *www.dk.com*

Explore the solar system, study astronomy, and discover fun facts about space shuttles with *Eye Wonder: Space*. From the huge volcanos of Venus to the massive storms on Jupiter, Pluto, and the comets; to how astronauts sleep in space; to the secrets of the stars; to our future in space, every page lets the reader discover new and fascinating facts about our universe. A precursor to DK's award-winning Eyewitness series, *Eye Wonder* was specially developed for children aged 5 and older and features astonishing photography, offering a whole new level of information through powerful images. For ages 5 to 9.

My First Book About Outer Space. By Patricia J. Wynne and Donald M. Silver.



Dover Publications, 2015, 48 pp., Paperback. $4.99. *www.doverpublications.com*

Where do we live among the galaxies? What did people think before they could study the sky with telescopes? What happened to Pluto? Thirty-nine illustrations to color answer these and other questions about our solar system and beyond. Entertaining, easy-to-understand captions explain crater formation, constellations, weightlessness, space junk, and other fascinating subjects. For ages 8 to 12.

Lunar Rover with Astronaut 4D Puzzle.

Produced by 4D Master. $24.95. *www.4dmaster.com*

This four-dimensional puzzle is three-dimensional plus detail. It is challenging and fun, of collectible quality, and has a highly detailed finish. This 1:35 scale puzzle has 55 plastic pieces, and there is no need for paint or glue. For ages 8 and up.

On the Space Station.

By Carron Brown and Bee Johnson. Kane Miller, 2016, 36 pp., Hardcover. $12.99. *new.myubam.com*

What is life like on a space station? What do the astronauts do in space? What do they eat? Where do they sleep? What do they wear? Shine a light behind each page and see hidden pictures. Each page turn will take you another step forward on this exciting tour of a space station. For ages 4 to 8.

Calendar 2016

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

July

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

3–8 **Astronomical Society of Australia Annual Scientific Meeting,** Sydney, Australia. *http://www.asa2016.org*

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

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

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

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

17–21 **Transiting Exoplanets, Keele,** United Kingdom. *https://wasp-planets.net/conference/*

18–19 **Third International Conference on the Exploration of Phobos and Deimos,** Moffett Field, California. *http://phobos-deimos.arc.nasa.gov/*

19 **Lunar and Small Bodies Graduate Conference (LunGradCon 2016),** Mountain View, California. *http://impact.colorado.edu/lungradcon/2016/*

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

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

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

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

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

25–Aug 5 **Summer School in Software Systems for Astronomy,** Hilo, Hawaii. *http://phys.uhh.hawaii.edu/Summer2016/summer2016.php*

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

27–29 **Workshop Without Walls: Exoplanet Biosignatures,** Seattle, Washington. *http://nai.nasa.gov/calendar/workshop-without-walls-exoplanet-biosignatures/*

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

August

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

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

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

17–19 **7th Planetary Crater Consortium Meeting,** Providence, Rhode Island. *http://www.planetarycraterconsortium.nau.edu*

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

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

September

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

12–14 **Biosignatures of Extant Life on Ocean Worlds,** Greenbelt, Maryland. *http://ssed.gsfc.nasa.gov/BELOW/*

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

12–15 **SPICE Training Class,** Madrid, Spain. *http://www.cosmos.esa.int/web/spice/training-class-september-2016*

13–16 **Multiple Faces of Interstellar Dust,** Garching, Germany. *http://www.mpa-garching.mpg.de/~lana/DUST2016/*

20–23 **Half a Decade of ALMA: Cosmic Dawns Transformed,** Indian Wells, California. *http://go.nrao.edu/ALMA5years*

25–28 **Geological Society of America Meeting,** Denver, Colorado. *http://community.geosociety.org/gsa2016/home*

25–28 **Exoplanets in the Era of Extremely Large Telescopes,** Pacific Grove, California. *http://www.gmtconference.org*

26–27 **The 6th International Workshop on Lunar Surface Applications,** Bellevue, Washington. *http://www.lsaworkshops.com*

26–30 **67th International Astronautical Congress,** Guadalajara, Mexico. *http://www.iafastro.org/events/iac/iac2016/*

28–29 **The 6th International Workshop on LunarCubes,** Bellevue, Washington. *http://www.lsaworkshops.com/*

October

10–14 **The Seventh Moscow Solar System Symposium (7M-S3),** Moscow, Russia. *http://ms2016.cosmos.ru/*

16–21 **Joint 48th Division of Planetary Sciences (DPS) and 11th European Planetary Science Conference (EPSC),** Pasadena, California. *http://aas.org/meetings/dps48*

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

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

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

24–28 **Exploring the Universe with JWST — II,** Montreal, Canada. *http://craq-astro.ca/jwst2016/*

27–28 **SMA Science in the Next Decade,** Taipei, Taiwan. *http://events.asiaa.sinica.edu.tw/workshop/20161027/*

31–Nov 4 **Stardust Final Conference on Asteroids and Space Debris,** Noodwijk, The Netherlands. *http://www.stardust2013.eu/Training/Conferences/StardustFinalConference/Asteroids/tabid/5541/Default.aspx*

November

1–16 **XXVIII Canary Islands Winter School of Astrophics,** La Laguna, Spain. *http://www.iac.es/winterschool/2016/*

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

29–Dec 1 **14th Meeting of the Venus Exploration Analysis Group (VEXAG),** Washington, DC. *http://www.lpi.usra.edu/vexag/*

December

11–16 **Search for Life: From Early Earth to Exoplanets,** Quy Nhon, Vietnam. *http://rencontresduvietnam.org/conferences/2016/search-for-life/*

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

January 2017

3–7 **229th American Astronomical Society Meeting,** Grapevine, Texas. *http://aas.org/meetings/aas229*

11–13 **16th Meeting of the NASA Small Bodies Assessment Group (SBAG),** Tucson, Arizona. *http://www.lpi.usra.edu/sbag/*

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

23–27 **Ices in the Solar System,** Madrid, Spain. *http://www.cosmos.esa.int/web/ices-in-the-solar-system/home*

February

1–3 **21st International Microlensing Conference,** Pasadena, California. *http://nexsci.caltech.edu/conferences/2017/microlensing/*