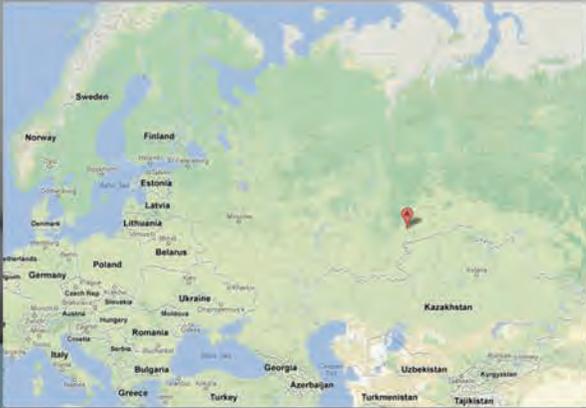


CHELYABINSK AIR BURST

A DRAMATIC ILLUSTRATION OF A
NEAR-EARTH ASTEROID IMPACT



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Chelyabinsk Air Burst

A Dramatic Illustration of a Near-Earth Asteroid Impact

— David A. Kring, Lunar and Planetary Institute

News headlines on Friday, February 15, 2013, alerted the world that a small near-Earth asteroid (NEA) penetrated Earth's atmosphere and catastrophically exploded over Russia, producing shock waves and an air blast that injured over a thousand people and damaged buildings in and around the city of Chelyabinsk. Like the impact of Comet Shoemaker-Levy 9 into Jupiter's atmosphere in 1994, the public saw, first hand, the effects of an impacting object.

The explosion startled the public and the scientific community, because the impacting object had gone undetected until it hit Earth. Scientists, however, mobilized immediately, both in Russia and elsewhere in the world. In North America, Bill Cooke of the Meteoroid Environment Office at NASA's Marshall Space Flight Center rapidly coordinated observations with a large number of investigators in the NEA community. Peter Brown and Margaret Campbell-Brown at the University of Western Ontario began to calculate the trajectory of the object and, importantly, the energy of the event from infrasound data captured by the International Monitoring System (IMS) operated by the Comprehensive Nuclear-Test-Ban Treaty Organization. Paul Chodas and his colleagues at NASA's Jet Propulsion Laboratory began to calculate the orbit and to obtain independent measurements of trajectory and energy of the event from U.S. government sensors. Mark Boslough began comparing and contrasting the event with the century-old Tunguska event, and I was tasked to use information gleaned from meteoritic and impact cratering studies to better interpret the blast. These and many other scientists throughout the international NEA and impact cratering communities answered questions from the public and provided input to their respective government officials.

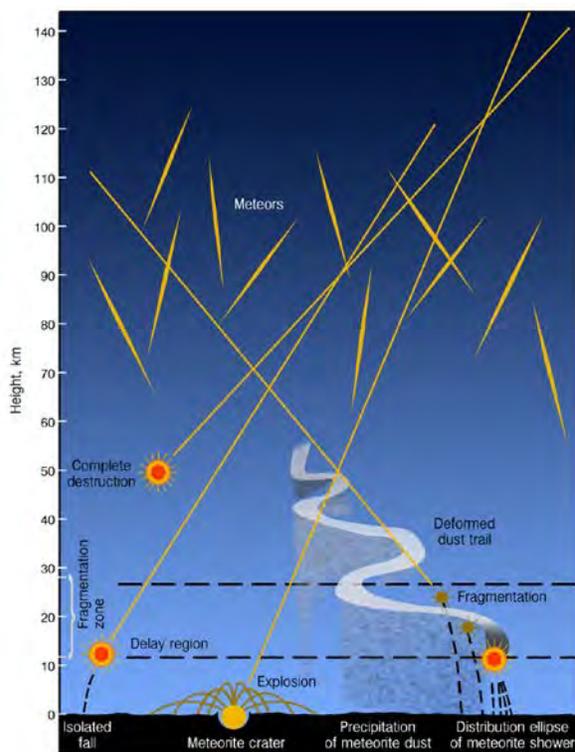


Fig. 1. The possible outcomes of impacting meteoroids, asteroids, and comets that hit the Earth's atmosphere. Modified after E. L. Krinov (1966).

Immediately after the explosion, the Chelyabinsk asteroid was estimated to have been about 17 meters in diameter, with a velocity of 17–18 kilometers per second, producing an ~500-kiloton explosion 15–20 kilometers above the Earth's surface. Final numbers are still being calculated, but the object is currently estimated to have been 20 meters in diameter, with a velocity of 18.6 kilometers per second, producing an ~440-kiloton explosion 23 kilometers above the Earth's surface. At the time the asteroid penetrated the Earth's atmosphere it was moving at supersonic speeds, approximately Mach 63 immediately prior to detonation, producing a ballistic shock wave and a split trailing plume. The dramatic terminal explosion created a second blast shock wave.

The event was roughly an order of magnitude more energetic than the Sikhote-Alin event of 1947 (~10 kilotons) and roughly an order of magnitude less energetic than the Tunguska event of 1908 (2–15 megatons). There is considerable uncertainty in the energy of Tunguska, Meteor Crater, and other relatively small impact events, which has undermined efforts to assess future hazards. For that reason, the Chelyabinsk impact event is incredibly

Chelyabinsk Air Burst *continued . . .*

important: It will produce the first high-precision values for the energy of a blast and the corresponding ground damage it caused.

Fortunately, the Earth's atmosphere screens most objects from reaching the surface with cosmic velocities (Fig. 1). Sometimes objects are large enough and strong enough, however, to penetrate deeply into the atmosphere before exploding to produce an air burst (e.g., Tunguska) or a hypervelocity impact crater (e.g., Meteor Crater), both of which can generate dramatic effects on the Earth's surface.



Fig. 2. The Chelyabinsk asteroid was a brecciated LL-chondrite that had been previously damaged by impact processes. Credit: Svend Buhl/Meteor Recon.

The Chelyabinsk air burst suggested the object was a structurally weak stony asteroid, an assessment soon confirmed when surviving fragments were recovered by the Russian public and scientists (Fig. 2). The material appeared to be a type of ordinary chondrite, and was later classified as an LL ordinary chondrite. The surviving stones indicate the asteroid had suffered the effects of collisional events in the past, producing a breccia that is cross-cut with submillimeter- to centimeter-wide impact melt veins and multi-centimeter-wide impact melt pockets.

With a diameter of 20 meters, it surpassed the 6–8-meter-diameter Gold Basin NEA impact event as the largest documented stony asteroid air burst with surviving meteoritic fragments.

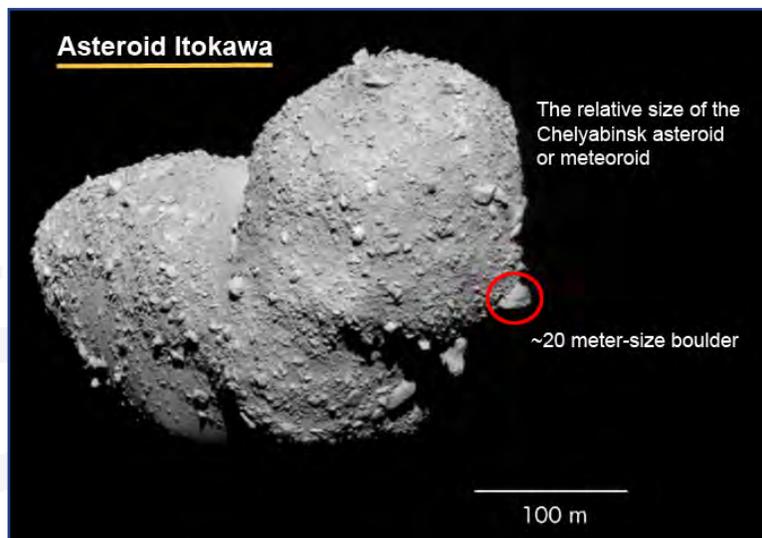


Fig. 3. The Chelyabinsk asteroid is compositionally related to the Itokawa NEA, which also has affinities with LL chondrites. Annotated illustration based on JAXA imagery.

We have about 40,000 ordinary chondrites in our collections, and nearly 6,000 of those have LL-chondrite affinities. In addition, the Japanese space agency, JAXA, returned to Earth samples from the Itokawa asteroid and showed that it, too, has LL-chondrite affinities. The Itokawa asteroid has a length of 540 meters and contains many boulders similar in size to the Chelyabinsk asteroid (Fig. 3). Both of those objects, however, are small compared to the original size of one or more LL-chondrite parent bodies, which are generally estimated to be ≥ 100 kilometers in diameter (Fig. 4). Numerous studies have shown that body to have had an extensive collisional history over the past 4.5 billion years. It is not yet clear if

the impact event(s) that shattered and melted portions of the Chelyabinsk material occurred on that parent body or after being ejected. The parent body is so large (Fig. 4) that it can produce a huge number of Itokawa- and Chelyabinsk-sized NEAs.

The Chelyabinsk impact event occurred a little more than 16 hours before the 20×40 -meter asteroid 2012 DA₁₄ passed within 27,700 kilometers of Earth's surface, generating a lot of public speculation

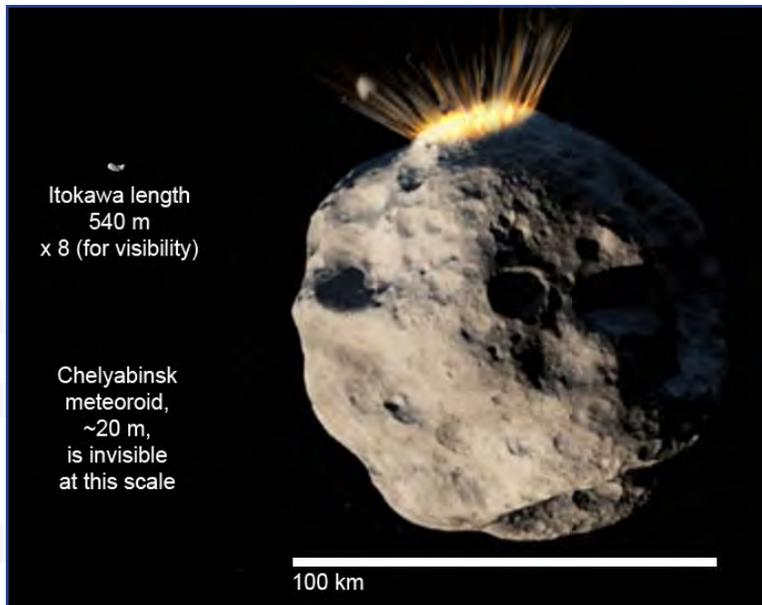


Fig. 4. The material in the Chelyabinsk and Itokawa asteroids are related to the LL-chondrite family, which came from one or more parent bodies that were originally ≥ 100 kilometers in diameter; i.e., there may be many other objects like Chelyabinsk and Itokawa in near-Earth space. Composite image using a detail from artwork by Daniel D. Durda for the LPI-JSC Center for Lunar Science and Exploration.

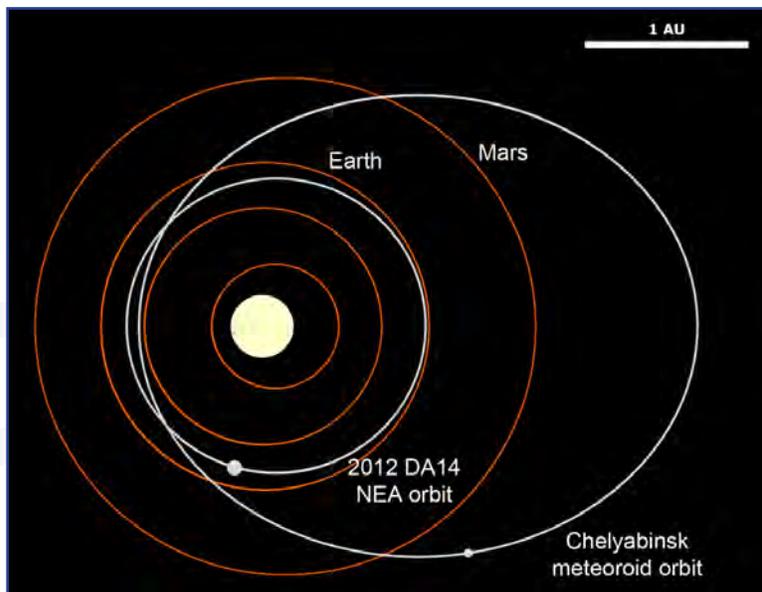


Fig. 5. The relative orbits of the Chelyabinsk and 2012 DA14 asteroids were very different.

that the two events were related. Scientists and space agency officials were able to immediately quench those rumors and any fears that other fragments of 2012 DA₁₄ might hit Earth. The orbits of those two NEAs were much different (Fig. 5). The Chelyabinsk asteroid had an apogee in the asteroid belt, whereas 2012 DA₁₄ has a near-circular orbit. The latter indicates 2012 DA₁₄ was perturbed from the main DA₁₄ belt millions of years before the Chelyabinsk asteroid. Furthermore, spectral analyses of 2012 DA₁₄ by Nicholas Moskovitz and Richard Binzel at the Massachusetts Institute of Technology suggest that it is related to carbonaceous chondrites, rather than the ordinary chondritic material of Chelyabinsk.

The Chelyabinsk event was featured in a special session added to the IAA Planetary Defense Conference, which was hosted by David Trilling and others in Flagstaff, Arizona, on April 14–19. David Morrison, Mark Boslough, Clark Chapman, and Alan Harris organized the special session and asked Peter Brown to summarize observations, Paul Chodas to discuss the trajectory and orbit of the impactor, Mark Boslough to show his computer simulation of the air burst, Peter Jenniskens to describe circumstances on the ground in the blast zone, and me to provide a geologic and meteoritic perspective of the event. During the remainder of the meeting, the community explored the hazards of near-Earth objects, existing and proposed detection programs, and mitigation strategies. Moreover, the community was briefed on discussions occurring between NASA and the Federal

Emergency Management Agency (FEMA) to prepare the U.S. for a future impact event. On the final day of the conference, the community was asked to participate in a simulation of an impact scenario.

With agency officials observing, an emergency response exercise was conducted for a hypothetical impact of an asteroid. The exercise utilized teams designed to characterize the asteroid; develop mitigation techniques and missions; calculate potential impact consequences; develop an emergency management and education response; and represent nations within the risk corridor, the United Nations and other international organizations, the media, and the space agencies. The teams were told that a 300-meter stony asteroid had been detected with a small but non-negligible probability of impact, and an orbit that generated a circular risk corridor that passed over portions of the Arctic, Europe, North Africa, and around the world until it passed over the eastern coast of China, and then back toward the Arctic. As the simulation proceeded, details of the impacting object were uncovered, all efforts to deflect or destroy the object failed, and preparations for impact became increasingly important. It was a riveting exercise for many scientists in the community, and one that identified several issues that need to be addressed to enhance the world's preparedness for impact events the size of Chelyabinsk and larger.

Cover images:

Top and bottom: YouTube screen capture of still shots taken from a video of the massive fireball streaking through the air in Chelyabinsk, Russia, on Friday, February 15.

Inset top: Map showing the location of Chelyabinsk in central Russia.

Inset bottom: The Chelyabinsk asteroid was a brecciated LL-chondrite that had been previously damaged by impact processes. Credit: Svend Buhl/Meteor Recon.

About the Author:



Dr. David Kring is a senior staff scientist at the Lunar and Planetary Institute in Houston, Texas. His research explores the origin of the solar nebula and its evolution into a geologically active planetary system; the geologic history of the Earth, Moon, Mars, and several smaller planetary bodies; impact cratering on the Earth, its effect on Earth's environment, and its possible role in the biological evolution of our planet; and the chemical and physical properties of meteorites. He has worked extensively with the Chicxulub impact crater and the

Cretaceous-Tertiary mass extinction event. That led to an astrobiologically-relevant examination of the environmental and biological consequences of impact cratering throughout Earth history, including an inner solar system bombardment approximately 4 billion years ago. He is currently integrating his field experience in impact-cratered and volcanic terrains with his analytical experience of Apollo, Luna, and meteorite sample collections to assist training and mission simulations needed to advance the nation's human and robotic exploration programs.



The Lunar Atmosphere and Dust Environment Explorer (LADEE) is designed to study the Moon's thin exosphere and the lunar dust environment. Credit: NASA/Ames/GFSC.

LADEE Mission Prepares for Launch

NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) Observatory recently completed the Thermal-Vacuum (TVAC) phase of environmental testing at NASA's Ames Research Center, Moffett Field, California. During the TVAC environmental testing phase, LADEE underwent a variety of rigorous tests that simulate the full range of extreme temperatures and vacuum the spacecraft will experience during the course of its mission. The successful completion of this phase of testing means NASA engineers are confident that LADEE will be able to operate in the harsh conditions of space. Launch is currently scheduled for August 2013. Previous mechanical tests — including acoustic, vibration, and shock — confirmed the LADEE Observatory is able to withstand the loud, shaking launch conditions the spacecraft must endure to reach orbit.

Now that the TVAC tests are complete, engineers will test LADEE's radio communication system to ensure it is compatible with NASA's Near-Earth and Deep Space Communication Networks. To perform these communications tests, equipment will be brought to NASA Ames and connected to the spacecraft to exercise the communications modes that will be used during the mission. It is important to test the LADEE communications system with both communication networks prior to launch, so that the Mission Operations Team at NASA Ames can prepare for the initial contact with the spacecraft.

After LADEE separates from the upper stage of the Minotaur V launch vehicle, the spacecraft will power on. At that time, the Mission Operations Team at NASA Ames will use the Near-Earth Space network to make initial contact with LADEE. After initial contact, the team will establish positive control of the spacecraft so that they can maneuver LADEE into a phasing orbit that will take it to the Moon. LADEE will loop around Earth to gradually raise its orbit and position so that it can fire its engines and enter lunar orbit. During the trajectory maneuvers on its way to the Moon, LADEE will transmit to NASA's Deep Space Network ground stations located around the globe. LADEE also will use this network to send science data back to Earth during the mission's science phase.

In order to understand Earth's atmosphere and how it works, it is essential to study atmospheres under a wide range of conditions beyond Earth. Examining atmospheres on other planets allows this. For example, by studying the atmosphere of Venus, we learned about the role of carbon dioxide as a greenhouse gas, and saw how it drives the temperature on Venus as high as 860°F (460°C). The Moon has a type of atmosphere scientists call a surface boundary exosphere. This very thin atmosphere may actually be the most common type of atmosphere in our solar system. Yet despite occurring so frequently, surface boundary exospheres largely remain a mystery. The Moon, Mercury, larger asteroids, many moons orbiting the solar system's giant planets, and even some of the distant Kuiper belt objects beyond Neptune all have surface boundary exospheres.

To fully understand atmospheres and how they work, we also need to understand the most common type. Fortunately, the Moon is in our own celestial "backyard," and LADEE's observations of the lunar

atmosphere and surface conditions will provide us with insights we can apply to many worlds and to Earth's atmosphere.

For more information about the LADEE mission, visit www.nasa.gov/LADEE.



Meteoritic samples of asteroid Vesta have been used to determine that it was hit by a flurry of other asteroids roughly four billion years ago. This sample of fragmented rock was produced by those impact events when they tore up basaltic lava flows and solidified subsurface magma chambers to produce an impact breccia. The sample is seen on a microscope used to study these types of meteoritic samples of the asteroid belt. Photograph by Dr. David A. Kring/LPI/CLSE.

NASA-Supported Lunar Scientists Find New Link In Solar-System-Wide Impact Bombardment

Large asteroids like Vesta share a surprising history with Earth's Moon, according to a team of researchers from the NASA Lunar Science Institute (NLSI). The heavily cratered surface of the Moon and that of Vesta were apparently produced by the same population of high-speed projectiles four billion years ago.

The radiometric ages of lunar rocks collected by Apollo astronauts have long been used to study the bombardment history of the Moon. Similarly, the impact reset ages of meteorites have been used to study the collisional history of main-belt asteroids. In particular, howardite and eucrite meteorites (common species in our meteorite collections) have been used to study asteroid Vesta, their parent body. Now, for the first time, an international team of researchers

show that the same projectiles responsible for making craters and basins on the Moon were also hitting Vesta at very high velocities, enough to leave behind a number of telltale impact-related ages.

This research has been possible thanks to a multi-disciplinary work, including geochemistry, dynamics, simulations of impact events, and spacecraft observations. The findings were published in the March issue of *Nature Geoscience* in an article entitled "High Velocity Collisions from the Lunar Cataclysm Recorded in Asteroidal Meteorites." With the aid of computer simulations, the researchers determined that meteorites from Vesta recorded impacts by unusually high-speed projectiles that are now long gone. They deduced that this period of bombardment was related to a possible dramatic time in solar system history four billion years ago when gas giant planets like Jupiter and Saturn were migrating from their original orbits to where we see them today. The team's findings support the theory that this repositioning of the gas giant planets destabilized portions of the asteroid belt and triggered a solar-system-wide bombardment of asteroids. This event, called the "lunar cataclysm," pulled many asteroids into orbits that collided with Earth and the Moon. The research provides new constraints on the start and duration of the lunar cataclysm, and it demonstrates that the cataclysm was an event that affected not only the inner solar system planets, but asteroid belts as well.

The team's interpretation of the howardites and eucrites was augmented by recent close-in observations of Vesta's surface by NASA's Dawn spacecraft. In addition, the team used the latest dynamical models of early main-belt evolution to determine the likely source of these high-velocity impactors, and concluded that the same projectiles hitting Vesta also had orbits that struck the Moon at high speeds.

"It appears that the asteroidal meteorites show signs of the asteroid belt losing a lot of mass four billion years ago, with the escaped mass beating up on both the surviving main belt asteroids and the Moon at high speeds," says lead author Simone Marchi, who has a joint appointment between two NLSI teams, the

Center for Lunar Origin and Evolution (CLOE) at the Southwest Research Institute (SwRI) in Boulder, Colorado, and the Center for Lunar Science and Exploration (CLSE) at the Lunar and Planetary Institute (LPI) in Houston, Texas. “Our research not only supports the current theory, but it takes it to the next level of understanding.”

This research unveils an unexpected link between Vesta and the Moon, providing new means for studying the early bombardment history of the terrestrial planets. “It is extraordinary to think that we can hold in our hands samples of rock produced by impact processes that reshaped the solar system,” said David Kring of CLSE.

The paper is available online at www.nature.com/ngeo/journal/vaop/ncurrent/pdf/ngeo1769.pdf.



This image from cameras on NASA’s Mars Reconnaissance Orbiter documents the appearance of a new cluster of impact craters on Mars. The orbiter has imaged at least 248 fresh craters, or crater clusters, on Mars. Credit: NASA/JPL-Caltech/MSSS/ Univ. of Arizona.

NASA Probe Counts Space Rock Impacts on Mars

Scientists using images from NASA’s Mars Reconnaissance Orbiter (MRO) have estimated that the planet is bombarded by more than 200 small asteroids or bits of comets per year forming craters at least 12.8 feet (3.9 meters) across. Researchers have identified 248 new impact sites on parts of the martian surface in the past decade, using images from the spacecraft to determine when the craters appeared. The 200-per-year planetwide estimate is a calculation based on the number found in a systematic survey of a portion of the planet.

MRO’s High Resolution Imaging Science Experiment (HiRISE) camera took pictures of the fresh craters at sites where before-and-after images by other cameras bracketed when the impacts occurred. This combination provided a new way to make direct measurements of the impact rate on Mars. This will lead to better age estimates of recent features on

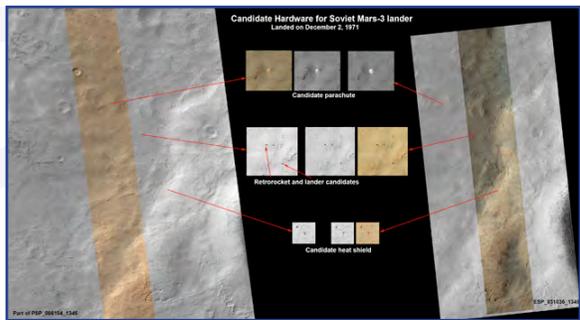
Mars, some of which may have been the result of climate change. “It’s exciting to find these new craters right after they form,” said Ingrid Daubar of the University of Arizona, Tucson, lead author of the paper published online this month by the journal *Icarus*. “It reminds you Mars is an active planet, and we can study processes that are happening today.”

These asteroids or comet fragments typically are no more than 3–6 feet (1–2 meters) in diameter. Space rocks too small to reach the ground on Earth cause craters on Mars because the Red Planet has a much thinner atmosphere. HiRISE targeted places where dark spots had appeared during the time between images taken by the spacecraft’s Context Camera (CTX) or cameras on other orbiters. The new estimate of cratering rate is based on a portion of the 248 new craters detected. It comes from a systematic check of a dusty fraction of the planet with CTX since late 2006. The impacts disturb the dust, creating noticeable blast zones. In this part of the research, 44 fresh impact sites were identified. The meteor over Chelyabinsk, Russia, in February (see cover story) was about 10 times bigger than the objects that dug the fresh martian craters.

Estimates of the rate at which new craters appear serve as scientists’ best yardstick for estimating the ages of exposed landscape surfaces on Mars and other worlds. Daubar and co-authors calculated a rate for how

frequently new craters at least 12.8 feet (3.9 meters) in diameter are excavated. The rate is equivalent to an average of one each year on each area of the martian surface roughly the size of the U.S. state of Texas. Earlier estimates pegged the cratering rate at 3–10 times more craters per year. They were based on studies of craters on the Moon and the ages of lunar rocks collected during NASA's Apollo missions in the late 1960s and early 1970s.

“Mars now has the best-known current rate of cratering in the solar system,” said HiRISE Principal Investigator Alfred McEwen of the University of Arizona, a co-author on the paper. To see images of the craters, visit uahirise.org/sim.



This set of images shows what might be hardware from the Soviet Union's 1971 Mars 3 lander, seen in a pair of images from the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter. Credit: NASA/JPL-Caltech/Univ. of Arizona.

to transmit anything. Images of the possible Mars 3 features, taken by the High Resolution Imaging Science Experiment (HiRISE) camera on MRO, are available at uahirise.org/ESP_031036_1345 and www.jpl.nasa.gov/spaceimages/details.php?id=PIA16920. “Together, this set of features and their layout on the ground provide a remarkable match to what is expected from the Mars 3 landing, but alternative explanations for the features cannot be ruled out,” said HiRISE Principal Investigator Alfred McEwen of the University of Arizona, Tucson. “Further analysis of the data and future images to better understand the three-dimensional shapes may help to confirm this interpretation.”

In 1971, the former Soviet Union launched the Mars 2 and Mars 3 missions to Mars. Each consisted of an orbiter plus a lander. Both orbiter missions succeeded, although the surface of Mars was obscured by a planet-encircling dust storm. The Mars 2 lander crashed. Mars 3 became the first successful soft landing on the Red Planet, but stopped transmitting after just 14.5 seconds for unknown reasons.

The predicted landing site was at latitude 45°S, longitude 202°E, in Ptolemaeus Crater. HiRISE acquired a large image at this location in November 2007. This image contains 1.8 billion pixels of data, so about 2500 typical computer screens would be needed to view the entire image at full resolution. Promising candidates for the hardware from Mars 3 were found on December 31, 2012.

Vitali Egorov from St. Petersburg, Russia, heads the largest Russian Internet community about Curiosity, at vk.com/curiosity_live. His subscribers did the preliminary search for Mars 3 via crowdsourcing. Egorov modeled what Mars 3 hardware pieces should look like in a HiRISE image, and the group carefully searched the many small features in this large image, finding what appear to be viable candidates in the southern part of the scene. Each candidate has a size and shape consistent with the expected hardware, and they are arranged on the surface as expected from the entry, descent, and landing sequence. “I wanted

NASA Mars Orbiter Images May Show 1971 Soviet Lander

Hardware from a spacecraft that the Soviet Union landed on Mars in 1971 might appear in images from NASA's Mars Reconnaissance Orbiter (MRO). While following news about Mars and NASA's Curiosity rover, Russian citizen enthusiasts found four features in a five-year-old image from MRO that resemble four pieces of hardware from the Soviet Mars 3 mission: the parachute, heat shield, terminal retrorocket, and lander. A follow-up image by MRO from March shows the same features.

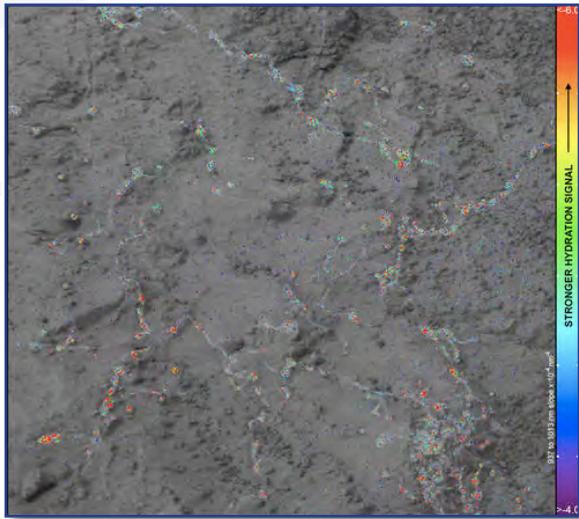
The Mars 3 lander transmitted for several seconds after landing on December 2, 1971, the first spacecraft to survive a Mars landing long enough

to attract people's attention to the fact that Mars exploration today is available to practically anyone," Egorov said. "At the same time we were able to connect with the history of our country, which we were reminded of after many years through the images from the Mars Reconnaissance Orbiter."

An advisor to the group, Alexander Basilevsky of the Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, contacted McEwen suggesting a follow-up image. HiRISE acquired the follow-up on March 10, 2013. This image was targeted to cover some of the hardware candidates in color and to get a second look with different illumination angles. Meanwhile, Basilevsky and Egorov contacted Russian engineers and scientists who worked on Mars 3 for more information.

For more information about MRO, which has been studying Mars from orbit since 2006, visit www.nasa.gov/mro.

Curiosity Mars Rover Sees Trend In Water Presence



On this image of the rock target "Knorr," color coding maps the amount of mineral hydration indicated by a ratio of near-infrared reflectance intensities measured by the Mast Camera (Mastcam) on NASA's Mars rover Curiosity. The color scale on the right shows the assignment of colors for relative strength of the calculated signal for hydration. The map shows that the stronger signals for hydration are associated with pale veins and light-toned nodules in the rock. This image and the data for assessing hydration come from a Mastcam observation of Knorr during the 133rd martian day (sol) of Curiosity's work on Mars (December 20, 2012). The width of the area shown in the image is about 10 inches (25 centimeters). Credit: NASA/JPL-Caltech/MSSS/ASU.

NASA's Mars rover Curiosity has seen evidence of water-bearing minerals in rocks near where it had already found clay minerals inside a drilled rock. Two weeks ago, the rover's science team announced that analysis of powder from a drilled mudstone rock on Mars indicates past environmental conditions that were favorable for microbial life. Additional findings presented in March at a news briefing at the Lunar and Planetary Science Conference in The Woodlands, Texas, suggest those conditions extended beyond the site of the drilling.

Using infrared-imaging capability of a camera on the rover and an instrument that shoots neutrons into the ground to probe for hydrogen, researchers have found more hydration of minerals near the clay-bearing rock than at locations Curiosity visited earlier.

The rover's Mast Camera (Mastcam) can also serve as a mineral-detecting and hydration-detecting tool, reported Jim Bell of Arizona State University, Tempe. "Some iron-bearing rocks and minerals can be detected and mapped using the Mastcam's near-infrared filters." Ratios of brightness in different Mastcam near-infrared wavelengths can indicate the presence of some hydrated minerals. The technique was used to check rocks in the "Yellowknife Bay" area where Curiosity's drill last month collected the first powder from the interior of a rock on Mars. Some rocks in Yellowknife Bay are crisscrossed with bright veins.

"With Mastcam, we see elevated hydration signals in the narrow veins that cut many of the rocks in this area," said Melissa Rice of the California Institute of Technology, Pasadena. "These bright veins contain hydrated minerals that are different from the clay minerals in the surrounding rock matrix."

The Russian-made Dynamic Albedo of Neutrons (DAN) instrument on Curiosity detects hydrogen beneath the rover. At the rover's very dry study area on Mars, the detected hydrogen is mainly in water molecules bound into minerals. "We definitely see signal variation along the traverse from the landing point to Yellowknife Bay," said DAN Deputy Principal Investigator Maxim Litvak of the Space Research Institute, Moscow. "More water is detected at Yellowknife Bay than earlier on the route. Even within Yellowknife Bay, we see significant variation."

Findings presented from the Canadian-made Alpha Particle X-ray Spectrometer (APXS) on Curiosity's arm indicate that the wet environmental processes that produced clay at Yellowknife Bay did so without much change in the overall mix of chemical elements present. The elemental composition of the outcrop Curiosity drilled into matches the composition of basalt. For example, it has basalt-like proportions of silicon, aluminum, magnesium, and iron. Basalt is the most common rock type on Mars. It is igneous, but it is also thought to be the parent material for sedimentary rocks Curiosity has examined.

For more information, visit mars.jpl.nasa.gov/msl or www.nasa.gov/mars, or follow the mission at www.facebook.com/MarsCuriosity and twitter.com/marscuriosity.



This set of images compares rocks seen by NASA's Opportunity rover and Curiosity rover at two different parts of Mars. On the left is "Wopmay" rock, in Endurance Crater, Meridiani Planum, as studied by the Opportunity rover. Credit: NASA/JPL-Caltech/Cornell/MSSS.

NASA Rover Finds Conditions Once Suited for Ancient Life on Mars

An analysis of a rock sample collected by NASA's Curiosity rover shows that ancient Mars could have supported living microbes. Scientists identified sulfur, nitrogen, hydrogen, oxygen, phosphorus, and carbon — some of the key chemical ingredients for life — in the powder Curiosity drilled out of a sedimentary rock near an ancient stream bed in Gale Crater on the Red Planet in February. "A fundamental question for this mission is whether Mars could have supported a habitable environment," said Michael Meyer, lead scientist for NASA's Mars Exploration Program at the agency's headquarters in Washington. "From what we know now, the answer is yes."

Clues to this habitable environment come from data returned by the rover's Sample Analysis at Mars (SAM) and Chemistry and Mineralogy (CheMin) instruments. The data indicate the Yellowknife Bay area the rover is exploring was the end of an ancient river system or an intermittently wet lake bed that could have provided chemical energy and other favorable conditions for microbes. The rock is made up of a fine-grained mudstone containing clay minerals, sulfate minerals, and other chemicals. This ancient wet environment, unlike some others on Mars, was not harshly oxidizing, acidic, or extremely salty.

The patch of bedrock where Curiosity drilled for its first sample lies in an ancient network of stream channels descending from the rim of Gale Crater. The bedrock also is fine-grained mudstone and shows evidence of multiple periods of wet conditions, including nodules and veins. Curiosity's drill collected the sample at a site just a few hundred yards away from where the rover found an ancient streambed in September 2012.

"Clay minerals make up at least 20 percent of the composition of this sample," said David Blake, principal investigator for the CheMin instrument at NASA's Ames Research Center. These clay minerals are a product of the reaction of relatively fresh water with igneous minerals, such as olivine, also present

in the sediment. The reaction could have taken place within the sedimentary deposit, during transport of the sediment, or in the source region of the sediment. The presence of calcium sulfate along with the clay suggests the soil is neutral or mildly alkaline.

Scientists were surprised to find a mixture of oxidized, less-oxidized, and even non-oxidized chemicals, providing an energy gradient of the sort many microbes on Earth exploit to live. This partial oxidation was first hinted at when the drill cuttings were revealed to be gray rather than red. “The range of chemical ingredients we have identified in the sample is impressive, and it suggests pairings such as sulfates and sulfides that indicate a possible chemical energy source for micro-organisms,” said Paul Mahaffy, principal investigator of the SAM suite of instruments at NASA’s Goddard Space Flight Center.



This image shows the first holes into rock drilled by NASA’s Mars rover Curiosity, with drill tailings around the holes plus piles of powdered rock collected from the deeper hole and later discarded after other portions of the sample had been delivered to analytical instruments inside the rover. Credit: NASA/JPL-Caltech/MSSS.

different atomic weights. “We found arguably the clearest and most robust signature of atmospheric loss on Mars,” said Sushil Atreya, a SAM co-investigator at the University of Michigan, Ann Arbor. SAM found that the martian atmosphere has about four times as much of a lighter stable isotope (argon-36) compared to a heavier one (argon-38). This removes previous uncertainty about the ratio in the martian atmosphere from 1976 measurements from NASA’s Viking project and from small volumes of argon extracted from martian meteorites. The ratio is much lower than the solar system’s original ratio, as estimated from argon-isotope measurements of the Sun and Jupiter. This points to a process at Mars that favored preferential loss of the lighter isotope over the heavier one.

Curiosity measures several variables in today’s martian atmosphere with the Rover Environmental Monitoring Station (REMS), provided by Spain. While daily air temperature has climbed steadily since the measurements began in August and is not strongly tied to the rover’s location, humidity has differed significantly at different places along the rover’s route. These are the first systematic measurements of humidity on Mars.

Trails of dust devils have not been seen inside Gale Crater, but REMS sensors detected many whirlwind patterns during the first hundred martian days of the mission, although not as many as detected in the same length of time by earlier missions. “A whirlwind is a very quick event that happens in a few seconds and should be verified by a combination of pressure, temperature, and wind oscillations and, in some cases, a decrease in ultraviolet radiation,” said REMS Principal Investigator Javier Gómez-Elvira of the Centro de Astrobiología in Madrid.

Remaining Martian Atmosphere Still Dynamic

Mars has lost much of its original atmosphere, but what’s left remains quite active, recent findings from NASA’s Mars rover Curiosity indicate. Rover team members reported diverse findings in April at the European Geosciences Union 2013 General Assembly, in Vienna. Evidence has strengthened that Mars lost much of its original atmosphere by a process of gas escaping from the top of the atmosphere.

Curiosity’s Sample Analysis at Mars (SAM) instrument analyzed an atmosphere sample using a process that concentrates selected gases. The results provided the most precise measurements ever made of isotopes of argon in the martian atmosphere.

Isotopes are variants of the same element with

Dust distributed by the wind has been examined by Curiosity's laser-firing Chemistry and Camera (ChemCam) instrument. Initial laser pulses on each target hit dust. The laser's energy removes the dust to expose underlying material, but those initial pulses also provide information about the dust. "We knew that Mars is red because of iron oxides in the dust," said ChemCam Deputy Principal Investigator Sylvestre Maurice of the Institut de Recherche en Astrophysique et Planétologie in Toulouse, France. "ChemCam reveals a complex chemical composition of the dust that includes hydrogen, which could be in the form of hydroxyl groups or water molecules."

Possible interchange of water molecules between the atmosphere and the ground is studied by a combination of instruments on the rover, including the Dynamic Albedo of Neutrons (DAN), provided by Russia under the leadership of DAN Principal Investigator Igor Mitrofanov.



The dark hot spot in this false-color image from the Cassini spacecraft is a window deep into Jupiter's atmosphere. All around it are layers of higher clouds, with colors indicating which layer of the atmosphere the clouds are in. Credit: NASA/JPL-Caltech/SSI/GSFC.

Cloudless "Hot Spots" Ride a Merry-Go-Round on Jupiter

In the swirling canopy of Jupiter's atmosphere, cloudless patches are so exceptional that the big ones get the special name "hot spots." Exactly how these clearings form and why they're only found near the planet's equator have long been mysteries. Now, using images from the Cassini spacecraft, scientists have found new evidence that hot spots in Jupiter's atmosphere are created by a Rossby wave, a pattern also seen in Earth's atmosphere and oceans. The team found the wave responsible for the hot spots glides up and down through layers of the atmosphere like a carousel horse on a merry-go-round. "This is the first time anybody has closely tracked the shape of

multiple hot spots over a period of time, which is the best way to appreciate the dynamic nature of these features," said the study's lead author, David Choi, a NASA Postdoctoral Fellow working at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The paper is published online in the April issue of the journal *Icarus*.

Choi and his colleagues made time-lapse movies (www.nasa.gov/mission_pages/cassini/whycassini/cassini20130314.html) from hundreds of observations taken by Cassini during its flyby of Jupiter in late 2000, when the spacecraft made its closest approach to the planet. The movies zoom in on a line of hot spots between one of Jupiter's dark belts and bright white zones, roughly 7° north of the equator. Covering about two months (in Earth time), the study examines the daily and weekly changes in the sizes and shapes of the hot spots, each of which covers more area than North America on average.

Much of what scientists know about hot spots came from NASA's Galileo mission, which released an atmospheric probe that descended into a hot spot in 1995. This was the first, and so far only, *in situ* investigation of Jupiter's atmosphere. "Galileo's probe data and a handful of orbiter images hinted at the complex winds swirling around and through these hot spots, and raised questions about whether they fundamentally were waves, cyclones, or something in between," said Ashwin Vasavada, a paper co-author who is based at NASA's Jet Propulsion Laboratory in Pasadena, California, and who was a member of the Cassini imaging team during the Jupiter flyby. "Cassini's fantastic movies now show the entire life cycle and evolution of hot spots in great detail."

Because hot spots are breaks in the clouds, they provide windows into a normally unseen layer of Jupiter's atmosphere, possibly all the way down to the level where water clouds can form. In pictures, hot

spots appear shadowy, but because the deeper layers are warmer, hot spots are very bright at the infrared wavelengths where heat is sensed; in fact, this is how they got their name. One hypothesis is that hot spots occur when big drafts of air sink in the atmosphere and get heated or dried out in the process. But the surprising regularity of hot spots has led some researchers to suspect there is an atmospheric wave involved. Typically, 8 to 10 hot spots line up, roughly evenly spaced, with dense white plumes of cloud in between. This pattern could be explained by a wave that pushes cold air down, breaking up any clouds, and then carries warm air up, causing the heavy cloud cover seen in the plumes. Computer modeling has strengthened this line of reasoning.

From the Cassini movies, the researchers mapped the winds in and around each hot spot and plume, and examined interactions with vortices that pass by, in addition to wind gyres, or spiraling vortices, that merge with the hot spots. To separate these motions from the jet stream in which the hot spots reside, the scientists also tracked the movements of small “scooter” clouds, similar to cirrus clouds on Earth. This provided what may be the first direct measurement of the true wind speed of the jet stream, which was clocked at about 300 to 450 miles per hour (500 to 720 kilometers per hour) — much faster than anyone previously thought. The hot spots amble at the more leisurely pace of about 225 miles per hour (362 kilometers per hour).

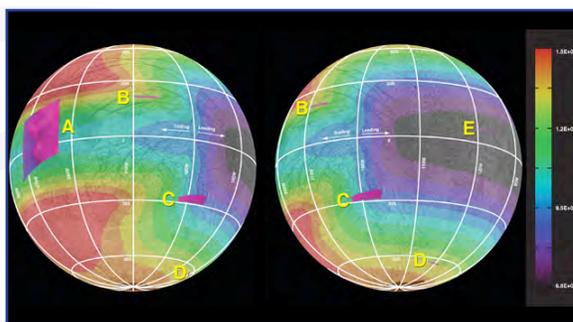
By teasing out these individual movements, the researchers saw that the motions of the hot spots fit the pattern of a Rossby wave in the atmosphere. On Earth, Rossby waves play a major role in weather. For example, when a blast of frigid Arctic air suddenly dips down and freezes Florida’s crops, a Rossby wave is interacting with the polar jet stream and sending it off its typical course. The wave travels around our planet but periodically wanders north and south as it goes. The wave responsible for the hot spots also circles the planet west to east, but instead of wandering north and south, it glides up and down in the atmosphere. The researchers estimate this wave may rise and fall 15 to 30 miles (24 to 50 kilometers) in altitude.

The new findings should help researchers understand how well the observations returned by the Galileo probe extend to the rest of Jupiter’s atmosphere. “And that is another step in answering more of the questions that still surround hot spots on Jupiter,” said Choi. For more information, visit www.nasa.gov/cassini or saturn.jpl.nasa.gov.

Where are the Best Windows Into Europa’s Interior?

The surface of Jupiter’s moon Europa exposes material churned up from inside the moon and also material resulting from matter and energy coming from above. If you want to learn about the deep saltwater ocean beneath this unusual world’s icy shell — as many people do who are interested in possible extraterrestrial life — you might target your investigation of the surface somewhere that has more of the up-from-below stuff and less of the down-from-above stuff. New analysis of observations made more than a decade ago by NASA’s Galileo mission to Jupiter helps identify those places.

“We have found the regions where charged electrons and ions striking the surface would have done the



This graphic of Jupiter’s moon Europa maps a relationship between the amount of energy deposited onto the moon from charged-particle bombardment and the chemical contents of ice deposits on the surface in five areas of the moon (labeled A through E). Credit: NASA/JPL-Caltech/Univ. of Ariz./JHUAPL/Univ. of Colo.

most, and the least, chemical processing of materials emplaced at the surface from the interior ocean,” said J. Brad Dalton of NASA’s Jet Propulsion Laboratory (JPL), lead author of a recent report published in the journal *Planetary and Space Science*. “That tells us where to look for materials representing the most pristine ocean composition, which would be the best places to target with a lander or study with an orbiter.”

Europa is about the size of Earth’s moon and, like our Moon, keeps the same side toward the planet it orbits. (Picture a car driving in circles around a mountain with its leftside windows always facing the mountain.) Europa’s orbit around Jupiter is filled with charged, energetic particles tied to Jupiter’s powerful magnetic field. Besides electrons, these particles include ions of sulfur and oxygen originating from volcanic eruptions on Io, a neighboring moon. The magnetic field carrying these energetic particles sweeps around Jupiter faster than Europa orbits Jupiter, in the same direction: about 10 hours per circuit for the magnetic field versus about 3.6 days for Europa’s orbit. So, instead of our mountain-circling car getting bugs on the front windshield, the bugs are plastered on the back of the car by a “wind” from behind going nearly nine times faster than the car. Europa has a “leading hemisphere” in front and a “trailing hemisphere” in back.

Dalton and his co-authors at JPL and at Johns Hopkins University Applied Physics Laboratory examined data from observations by Galileo’s near-infrared mapping spectrometer of five widely distributed areas of Europa’s surface. The spectra of reflected light from frozen material on the surface enabled them to distinguish between relatively pristine water and sulfate hydrates. These included magnesium and sodium sulfate salt hydrates, and hydrated sulfuric acid. They compared the distributions of these substances with models of how the influxes of energetic electrons and of sulfur and oxygen ions are distributed around the surface of Europa.

They found that the concentration of frozen sulfuric acid on the surface varies greatly. It ranges from undetectable levels near the center of the leading hemisphere, to more than half of the surface materials near the center of the heavily bombarded trailing hemisphere. The concentration was closely related to the amount of electrons and sulfur ions striking the surface. “The close correlation of electron and ion fluxes with the sulfuric acid hydrate concentrations indicates that the surface chemistry is affected by these charged particles,” says Dalton. “If you are interested in the composition and habitability of the interior ocean, the best places to study would be the parts of the leading hemisphere we have identified as receiving the fewest electrons and having the lowest sulfuric acid concentrations.”

Surface deposits in these areas are most likely to preserve the original chemical compounds that erupted from the interior. Dalton suggests that any future spacecraft missions to Europa should target these deposits for study from orbit, or even attempt to land there. “The darkest material, on the trailing hemisphere, is probably the result of externally-driven chemical processing, with little of the original oceanic material intact. While investigating the products of surface chemistry driven by charged particles is still interesting from a scientific standpoint, there is a strong push within the community to characterize the contents of the ocean and determine whether it could support life. These kinds of places just might be the windows that allow us to do that.”

Mapping the Chemistry Needed for Life at Europa

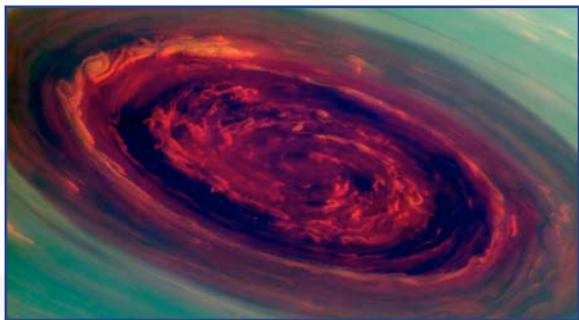
A new paper led by a NASA researcher shows that hydrogen peroxide is abundant across much of the surface of Jupiter’s moon Europa. The authors argue that if the peroxide on the surface of Europa mixes into the ocean below, it could be an important energy supply for simple forms of life, if life were to exist there. The paper was published online recently in *Astrophysical Journal Letters*. “Life as we know it needs liquid water, elements like carbon, nitrogen, phosphorus, and sulfur, and it needs some form of chemical or light energy to get the business of life done,” said Kevin Hand, the paper’s lead author,

based at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. "Europa has the liquid water and elements, and we think that compounds like peroxide might be an important part of the energy requirement. The availability of oxidants like peroxide on Earth was a critical part of the rise of complex, multicellular life."

The paper, co-authored by Mike Brown of the California Institute of Technology in Pasadena, analyzed data in the near-infrared range of light from Europa, using the Keck II Telescope on Mauna Kea, Hawaii, over four nights in September 2011. The highest concentration of peroxide found was on the side of Europa that always leads in its orbit around Jupiter, with a peroxide abundance of 0.12% relative to water. (For perspective, this is roughly 20 times more diluted than the hydrogen peroxide mixture available at drug stores.) The concentration of peroxide in Europa's ice then drops off to nearly zero on the hemisphere of Europa that faces backward in its orbit.

Hydrogen peroxide was first detected on Europa by NASA's Galileo mission, which explored the Jupiter system from 1995 to 2003, but Galileo observations were of a limited region. The new results show that peroxide is widespread across much of the surface of Europa, and the highest concentrations are reached in regions where Europa's ice is nearly pure water with very little sulfur contamination. The peroxide is created by the intense radiation processing of Europa's surface ice that comes from the moon's location within Jupiter's strong magnetic field. "The Galileo measurements gave us tantalizing hints of what might be happening all over the surface of Europa, and we've now been able to quantify that with our Keck telescope observations," Brown said. "What we still don't know is how the surface and the ocean mix, which would provide a mechanism for any life to use the peroxide."

The scientists think hydrogen peroxide is an important factor for the habitability of the global liquid water ocean under Europa's icy crust because hydrogen peroxide decays to oxygen when mixed into liquid water. "At Europa, abundant compounds like peroxide could help to satisfy the chemical energy requirement needed for life within the ocean, if the peroxide is mixed into the ocean," said Hand. For more information, visit www.keckobservatory.org and astrobiology.nasa.gov/nai.



The spinning vortex of Saturn's north polar storm resembles a deep red rose of giant proportions surrounded by green foliage in this false-color image from the Cassini spacecraft. Measurements have sized the eye at a staggering 1250 miles (2000 kilometers) across with cloud speeds as fast as 330 miles per hour (150 meters per second). Credit: NASA/JPL-Caltech/SSI.

NASA Probe Gets Close-Up Views of Large Hurricane on Saturn

NASA's Cassini spacecraft has provided scientists the first close-up, visible-light views of a behemoth hurricane swirling around Saturn's north pole. Images and a video of the hurricane are available at go.usa.gov/TQSB. In high-resolution pictures and video, scientists see the hurricane's eye is about 1250 miles (2000 kilometers) wide, 20 times larger than the average hurricane eye on Earth. Thin, bright clouds at the outer edge of the hurricane are traveling 330 miles per hour (150 meters per second). The hurricane swirls inside a large, mysterious, six-sided weather pattern known as the hexagon.

"We did a double take when we saw this vortex because it looks so much like a hurricane on Earth,"

said Andrew Ingersoll, a Cassini imaging team member at the California Institute of Technology in Pasadena. "But there it is at Saturn, on a much larger scale, and it is somehow getting by on the small amounts of water vapor in Saturn's hydrogen atmosphere." Scientists will be studying the hurricane to gain insight into hurricanes on Earth, which feed off warm ocean water. Although there is no body of

water close to these clouds high in Saturn's atmosphere, learning how these saturnian storms use water vapor could tell scientists more about how terrestrial hurricanes are generated and sustained.

Both a terrestrial hurricane and Saturn's north polar vortex have a central eye with no clouds or very low clouds. Other similar features include high clouds forming an eye wall, other high clouds spiraling around the eye, and a counterclockwise spin in the northern hemisphere. A major difference between the hurricanes is that the one on Saturn is much bigger than its counterparts on Earth and spins surprisingly fast. At Saturn, the wind in the eye wall blows more than four times faster than hurricane-force winds on Earth. Unlike terrestrial hurricanes, which tend to move, the saturnian hurricane is locked onto the planet's north pole. On Earth, hurricanes tend to drift northward because of the forces acting on the fast swirls of wind as the planet rotates. The one on Saturn does not drift and is already as far north as it can be. "The polar hurricane has nowhere else to go, and that's likely why it's stuck at the pole," said Kunio Sayanagi, a Cassini imaging team associate at Hampton University in Hampton, Virginia.

Scientists believe the massive storm has been churning for years. When Cassini arrived in the Saturn system in 2004, Saturn's north pole was dark because the planet was in the middle of its north polar winter. During that time, the Cassini spacecraft's composite infrared spectrometer and visual and infrared mapping spectrometer detected a great vortex, but a visible-light view had to wait for the passing of the equinox in August 2009. Only then did sunlight begin flooding Saturn's northern hemisphere. The view required a change in the angle of Cassini's orbits around Saturn so the spacecraft could see the poles.

Blame it on the Rain (from Saturn's Rings)

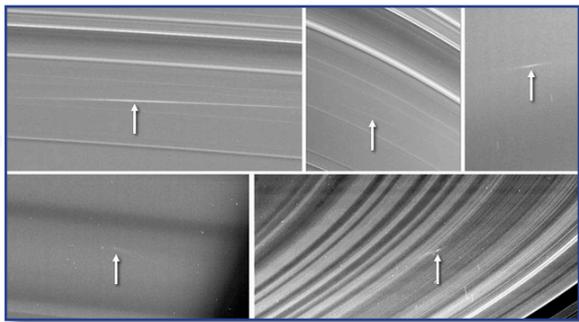
A new study tracks the "rain" of charged water particles into the atmosphere of Saturn and finds there is more of it and it falls across larger areas of the planet than previously thought. The study, whose observations were funded by NASA and whose analysis was led by the University of Leicester, England, reveals that the rain influences the composition and temperature structure of parts of Saturn's upper atmosphere. The paper appeared in an April issue of the journal *Nature*. "Saturn is the first planet to show significant interaction between its atmosphere and ring system," said James O'Donoghue, the paper's lead author and a postgraduate researcher at Leicester. "The main effect of ring rain is that it acts to 'quench' the ionosphere of Saturn. In other words, this rain severely reduces the electron densities in regions in which it falls."

O'Donoghue explains that the ring's effect on electron densities is important because it explains why, for many decades, observations have shown those densities to be unusually low at certain latitudes on Saturn. The study also helps scientists better understand the origin and evolution of Saturn's ring system and changes in the planet's atmosphere. "It turns out that a major driver of Saturn's ionospheric environment and climate across vast reaches of the planet are ring particles located some 36,000 miles [60,000 kilometers] overhead," said Kevin Baines, a co-author on the paper, based at NASA's Jet Propulsion Laboratory. "The ring particles affect both what species of particles are in this part of the atmosphere and where it is warm or cool." In the early 1980s, images from NASA's Voyager spacecraft showed two to three dark bands on Saturn, and scientists theorized that water could have been showering down into those bands from the rings. Those bands were not seen again until this team observed the planet in near-infrared wavelengths with the W. M. Keck Observatory on Mauna Kea, in Hawaii, in April 2011. The effect was difficult to discern because it involves looking for a subtle emission from bright parts of Saturn. It required an instrument like that on Keck, which can split up a large range of light.

The ring rain's effect occurs in Saturn's ionosphere, where charged particles are produced when the otherwise neutral atmosphere is exposed to a flow of energetic particles or solar radiation. When the scientists tracked the pattern of emissions of a particular hydrogen ion with three protons (triatomic hydrogen), they expected to see a uniform planet-wide infrared glow. What they observed instead was a

series of light and dark bands — with areas of reduced emission corresponding to water-dense portions of Saturn’s rings and areas of high emission corresponding to gaps in the rings. They surmised that charged water particles from the planet’s rings were being drawn toward the planet along Saturn’s magnetic field lines and were neutralizing the glowing triatomic hydrogen ions. This leaves large “shadows” in what would otherwise be a planet-wide infrared glow. These shadows cover some 30% to 43% of the planet’s upper atmosphere surface from around 25° to 55° latitude. This is a significantly larger area than suggested by images from the Voyager mission.

Both Earth and Jupiter have an equatorial region that glows very uniformly. Scientists expected this pattern at Saturn, too, but they instead saw dramatic differences at different latitudes. “Where Jupiter is glowing evenly across its equatorial regions, Saturn has dark bands where the water is falling in, darkening the ionosphere,” said Tom Stallard, a paper co-author at Leicester. “We’re now also trying to investigate these features with an instrument on NASA’s Cassini spacecraft. If we’re successful, Cassini may allow us to view in more detail the way that water is removing ionized particles, such as any changes in the altitude or effects that come with the time of day.”



Five images of Saturn’s rings, taken by the Cassini spacecraft between 2009 and 2012, show clouds of material ejected from impacts of small objects into the rings. Credit: NASA/JPL-Caltech/Space Science Institute/Cornell.

NASA Probe Observes Meteors Colliding with Saturn’s Rings

NASA’s Cassini spacecraft has provided the first direct evidence of small meteoroids breaking into streams of rubble and crashing into Saturn’s rings. These observations make Saturn’s rings the only location besides Earth, the Moon, and Jupiter where scientists and amateur astronomers have been able to observe impacts as they occur. Studying the impact rate of meteoroids from outside the saturnian system helps scientists understand how different planet systems in our solar system formed.

The solar system is full of small, speeding objects. These objects frequently pummel planetary bodies.

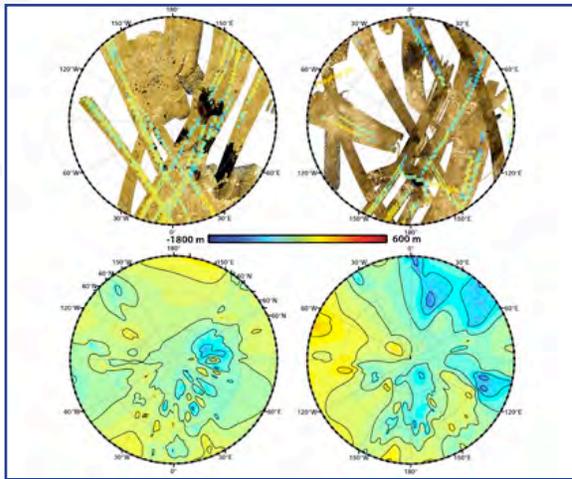
The meteoroids at Saturn are estimated to range from about one-half inch to several yards (1 centimeter to several meters) in size. It took scientists years to distinguish tracks left by nine meteoroids in 2005, 2009, and 2012. Details of the observations appeared in a paper in the Thursday, April 25, edition of *Science*.

Results from Cassini have already shown that Saturn’s rings act as very effective detectors of many kinds of surrounding phenomena, including the interior structure of the planet and the orbits of its moons. For example, a subtle but extensive corrugation that ripples 12,000 miles (19,000 kilometers) across the innermost rings tells of a very large meteoroid impact in 1983. “These new results imply the current-day impact rates for small particles at Saturn are about the same as those at Earth — two very different neighborhoods in our solar system — and this is exciting to see,” said Linda Spilker, Cassini project scientist at NASA’s Jet Propulsion Laboratory. “It took Saturn’s rings acting like a giant meteoroid detector — 100 times the surface area of the Earth — and Cassini’s long-term tour of the Saturn system to address this question.”

The saturnian equinox in summer 2009 was an especially good time to see the debris left by meteoroid impacts. The very shallow Sun angle on the rings caused the clouds of debris to look bright against the darkened rings in pictures from Cassini’s imaging science subsystem. “We knew these little impacts were constantly occurring, but we didn’t know how big or how frequent they might be, and we didn’t necessarily expect them to take the form of spectacular shearing clouds,” said Matt Tiscareno, lead author

of the paper and a Cassini participating scientist at Cornell University in Ithaca, New York. “The sunlight shining edge-on to the rings at the saturnian equinox acted like an anti-cloaking device, so these usually invisible features became plain to see.”

Tiscareno and his colleagues now think meteoroids of this size probably break up on a first encounter with the rings, creating smaller, slower pieces that then enter into orbit around Saturn. The impact into the rings of these secondary meteoroid bits kicks up the clouds. The tiny particles forming these clouds have a range of orbital speeds around Saturn. The clouds they form soon are pulled into diagonal, extended bright streaks. “Saturn’s rings are unusually bright and clean, leading some to suggest that the rings are actually much younger than Saturn,” said Jeff Cuzzi, a co-author of the paper and a Cassini interdisciplinary scientist specializing in planetary rings and dust at NASA’s Ames Research Center in Moffett Field, California. “To assess this dramatic claim, we must know more about the rate at which outside material is bombarding the rings. This latest analysis helps fill in that story with detection of impactors of a size that we weren’t previously able to detect directly.”



These polar maps show the first global, topographic mapping of Saturn’s moon Titan, using data from the Cassini mission. To create these maps, scientists employed a mathematical process called splining, which uses smooth curved surfaces to “join” the areas between grids of existing topography profiles obtained by Cassini’s radar instrument. Credit: NASA/JPL-Caltech/ASI/JHUAPL/Cornell/Weizmann.

Cassini Shapes First Global Topographic Map of Titan

Scientists have created the first global topographic map of Saturn’s moon Titan, giving researchers a valuable tool for learning more about one of the most Earth-like and interesting worlds in the solar system. The map was just published as part of a paper in the journal *Icarus*.

Titan is Saturn’s largest moon — at 1600 miles (2574 kilometers) across it’s bigger than Mercury — and is the second-largest moon in the solar system. Scientists care about Titan because it’s the only moon in the solar system known to have clouds; surface liquids; and a mysterious, thick atmosphere. The cold atmosphere is mostly nitrogen, like Earth’s, but the organic compound methane on Titan acts the way water vapor does on Earth, forming clouds and falling as rain and carving the surface with rivers. Organic chemicals, derived from methane, are present in Titan’s atmosphere, lakes, and rivers and may offer clues about the origins of life.

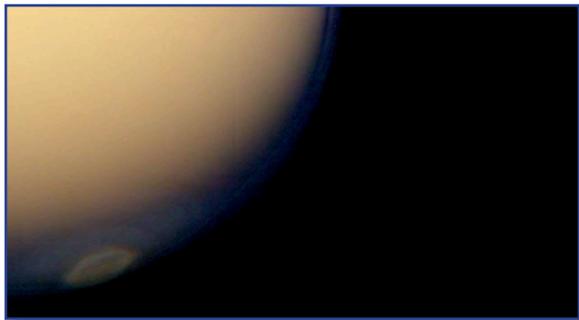
“Titan has so much interesting activity — like flowing liquids and moving sand dunes — but to understand these processes it’s useful to know how the terrain slopes,” said Ralph Lorenz, a member of the Cassini radar team based at the Johns Hopkins University Applied Physics Laboratory, who led the map-design team. “It’s especially helpful to those studying hydrology and modeling Titan’s climate and weather, who need to know whether there is high ground or low ground driving their models.”

Titan’s thick haze scatters light in ways that make it very hard for remote cameras to “see” landscape shapes and shadows, the usual approach to measuring topography on planetary bodies. Virtually all the data we have on Titan comes from the Saturn-orbiting Cassini spacecraft, which has flown past the moon nearly 100 times over the past decade. On many of those flybys, Cassini has used a radar imager, which can peer through the haze, and the radar data can be used to estimate the surface height. “With this new topographic map, one of the most fascinating and dynamic worlds in our solar system now pops out in

3-D,” said Steve Wall, the deputy team lead of Cassini’s radar team, based at NASA’s Jet Propulsion Laboratory. “On Earth, rivers, volcanoes, and even weather are closely related to heights of surfaces — we’re now eager to see what we can learn from them on Titan.”

There are challenges, however. “Cassini isn’t orbiting Titan,” Lorenz said. “We have only imaged about half of Titan’s surface, and multiple ‘looks’ or special observations are needed to estimate the surface heights. If you divided Titan into $1^\circ \times 1^\circ$ [latitude and longitude] squares, only 11% of those squares have topography data in them.”

Lorenz’s team used a mathematical process called splining — effectively using smooth, curved surfaces to “join” the areas between grids of existing data. “You can take a spot where there is no data, look how close it is to the nearest data, and use various approaches of averaging and estimating to calculate your best guess,” he said. “If you pick a point, and all the nearby points are high altitude, you’d need a special reason for thinking that point would be lower. We’re mathematically papering over the gaps in our coverage.” The estimations fit with current knowledge of the moon — that its polar regions are “lower” than areas around the equator, for example — but connecting those points allows scientists to add new layers to their studies of Titan’s surface, especially those modeling how and where Titan’s rivers flow, and the seasonal distribution of its methane rainfall. “The movement of sands and the flow of liquids are influenced by slopes, and mountains can trigger cloud formation and therefore rainfall. This global product now gives modelers a convenient description of this key factor in Titan’s dynamic climate system,” Lorenz said.



The recently formed south polar vortex stands out in the color-swaddled atmosphere of Saturn’s largest moon, Titan, in this natural color view from NASA’s Cassini spacecraft. Credit: NASA/JPL-Caltech/Space Science Institute.

Ice Cloud Heralds Fall at Titan’s South Pole

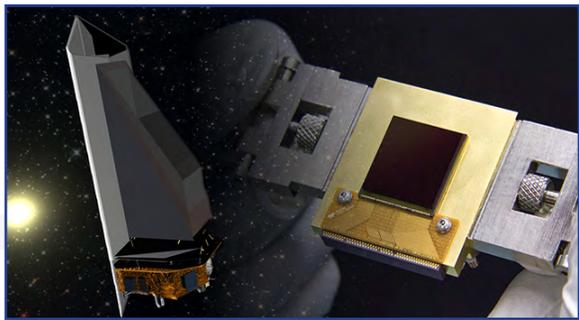
An ice cloud taking shape over Titan’s south pole is the latest sign that the change of seasons is setting off a cascade of radical changes in the atmosphere of Saturn’s largest moon. Made from an unknown ice, this type of cloud has long hung over Titan’s north pole, where it is now fading, according to observations made by the composite infrared spectrometer (CIRS) on NASA’s Cassini spacecraft. “We associate this particular kind of ice cloud with winter weather on Titan, and this is the first time we have detected it anywhere but the north pole,” said the study’s lead author, Donald E. Jennings, a CIRS Co-Investigator at NASA’s Goddard Space Flight Center.

The southern ice cloud, which shows up in the far-infrared part of the light spectrum, is evidence that an important pattern of global air circulation on Titan has reversed direction. When Cassini first observed the circulation pattern, warm air from the southern hemisphere was rising high in the atmosphere and was transported to the cold north pole. There, the air cooled and sank down to lower layers of the atmosphere and formed ice clouds. A similar pattern, called a Hadley cell, carries warm, moist air from Earth’s tropics to the cooler middle latitudes. Based on modeling, scientists had long predicted a reversal of this circulation once Titan’s north pole began to warm and its south pole began to cool. The official transition from winter to spring at Titan’s north pole occurred in August 2009. But because each of the moon’s seasons lasts about seven-and-a-half Earth years, researchers still did not know exactly when this reversal would happen or how long it would take.

The first signs of the reversal came in data acquired in early 2012, which came shortly after the start of southern fall on Titan, when Cassini images and visual and infrared mapping spectrometer data revealed the presence of a high-altitude “haze hood” and a swirling polar vortex at the south pole. Both features have long been associated with the cold north pole. Later, Cassini scientists reported that infrared observations of Titan’s winds and temperatures made by CIRS had provided definitive evidence of air sinking, rather than upwelling, at the south pole. By looking back through the data, the team narrowed down the change in circulation to within six months of the 2009 equinox.

Despite the new activity at the south pole, the southern ice cloud had not appeared yet. CIRS didn’t detect it until about July 2012, a few months after the haze and vortex were spotted in the south, according to the study published in *Astrophysical Journal Letters* in December 2012. “This lag makes sense because first the new circulation pattern has to bring loads and loads of gases to the south pole. Then, the air has to sink. The ices have to condense. And the pole has to be under enough shadow to protect the vapors that condense to form those ices,” said Carrie Anderson, a CIRS team member and Cassini participating scientist at Goddard. At first blush, the southern ice cloud seems to be building rapidly. The northern ice cloud, on the other hand, was present when Cassini first arrived and has been slowly fading the entire time the spacecraft has been observing it.

So far, the identity of the ice in these clouds has eluded scientists, though they have ruled out simple chemicals, such as methane, ethane, and hydrogen cyanide, which are typically associated with Titan. One possibility is that “species X,” as some team members call the ice, could be a mixture of organic compounds. “What’s happening at Titan’s poles has some analogy to Earth and to our ozone holes,” said the CIRS Principal Investigator, Goddard’s F. Michael Flasar. “And on Earth, the ices in the high polar clouds aren’t just window dressing: They play a role in releasing the chlorine that destroys ozone. How this affects Titan chemistry is still unknown. So it’s important to learn as much as we can about this phenomenon, wherever we find it.”



The NEOCam sensor (right) is the lynchpin for the proposed Near Earth Object Camera (NEOCam) space mission (left). Credit: NASA/JPL-Caltech/Teledyne.

NASA-Funded Asteroid Tracking Sensor Passes Key Test

An infrared sensor that could improve NASA’s future detecting and tracking of asteroids and comets has passed a critical design test. The test assessed performance of the Near Earth Object Camera (NEOCam) in an environment that mimicked the temperatures and pressures of deep space. NEOCam is the cornerstone instrument for a proposed new space-based asteroid-hunting telescope. Details of the sensor’s design and capabilities are published in the *Journal of Optical Engineering*.

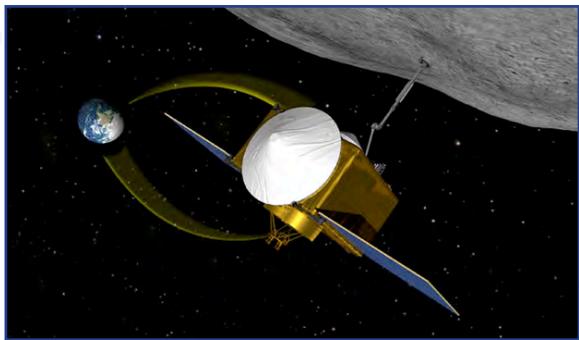
The sensor could be a vital component to inform plans for the agency’s recently announced initiative to develop the first-ever mission to identify, capture, and relocate an asteroid closer to Earth for future exploration by astronauts. “This sensor represents one of many investments made by NASA’s Discovery Program and its Astrophysics Research and Analysis Program in innovative technologies to significantly improve future missions designed to protect Earth from potentially hazardous asteroids,” said Lindley Johnson, program executive for NASA’s Near-Earth Object Program Office in Washington, DC.

Near-Earth objects are asteroids and comets with orbits that come within 28 million miles of Earth’s path around the Sun. Asteroids do not emit visible light; they reflect it. Depending on how reflective an object is, a small, light-colored space rock can look the same as a big, dark one. As a result, data collected

with optical telescopes using visible light can be deceiving. “Infrared sensors are a powerful tool for discovering, cataloging, and understanding the asteroid population,” said Amy Mainzer, a co-author of the paper and principal investigator for NASA’s Near-Earth Object Wide-Field Infrared Survey Explorer (NEOWISE) mission at the agency’s Jet Propulsion Laboratory. “When you observe a space rock with infrared, you are seeing its thermal emissions, which can better define the asteroid’s size, as well as tell you something about composition.”

The NEOCam sensor is designed to be more reliable and significantly lighter in weight for launching onboard spacebased telescopes. Once launched, the proposed telescope would be located about four times the distance between Earth and the Moon, where NEOCam could observe the comings and goings of NEOs every day without the impediments of cloud cover and daylight. “We were delighted to see in this generation of detectors a vast improvement in sensitivity compared with previous generations,” said the paper’s lead author, Craig McMurtry of the University of Rochester.

NASA’s NEOWISE is a continuation of the Wide-field Infrared Survey Explorer (WISE) mission, which launched in December 2009. The mission’s discoveries of previously unknown objects include 21 comets, more than 34,000 asteroids in the main belt between Mars and Jupiter, and 134 near-Earth objects. More information about asteroids and near-Earth objects is available at www.jpl.nasa.gov/asteroidwatch.



Artist's concept of the OSIRIS-REx mission. Credit: NASA/Goddard/University of Arizona.

NASA Spacecraft Will Visit Asteroid with New Name

An asteroid that will be explored by a NASA spacecraft has a new name, thanks to a third-grade student in North Carolina. NASA’s Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx) spacecraft will visit the asteroid now called Bennu, named after an important ancient Egyptian avian deity. OSIRIS-Rex is scheduled to launch in 2016, rendezvous with Bennu in 2018, and return a sample of the asteroid to Earth in 2023.

The name for the carbon-rich asteroid, designated in the scientific community as (101955) 1999 RQ36, is the winning entry in an international student contest. Nine-year-old Michael Puzio suggested the name because he imagined the Touch-and-Go Sample Mechanism (TAGSAM) arm and solar panels on OSIRIS-REx looking like the neck and wings in drawings of Bennu, which Egyptians usually depicted as a gray heron. In his entry, Puzio wrote that the name suits the asteroid because it means “the ascending one,” or “to shine.”

TAGSAM will collect a sample from Bennu and store it for return to Earth. The sample could hold clues to the origin of the solar system and the source of water and organic molecules that may have contributed to the development of life on Earth. The mission will be a vital part of NASA’s plans to find, study, capture, and relocate an asteroid for exploration by astronauts. NASA recently announced an asteroid initiative proposing a strategy to leverage human and robotic activities for the first human mission to an asteroid while also accelerating efforts to improve detection and characterization of asteroids.

“There were many excellent entries that would be fitting names and provide us an opportunity to educate the world about the exciting nature of our mission,” said Dante Lauretta of the University of Arizona in Tucson, a contest judge and the principal investigator of the OSIRIS-REx mission. “The information about the composition of Bennu and the nature of its orbit will enable us to explore our past and better

understand our future.” More than 8000 students from more than 25 countries worldwide, all younger than 18, entered the “Name that Asteroid!” contest last year. Each contestant submitted one name with a maximum of 16 characters and a short explanation for the name.

The contest was a partnership with The Planetary Society in Pasadena, California; the Massachusetts Institute of Technology Lincoln Laboratory in Lexington, Massachusetts; and the University of Arizona. The partners assembled a panel to review the submissions and submit a top choice to the International Astronomical Union (IAU) Committee for Small Body Nomenclature. The IAU is the governing body that officially names a celestial object. “Bennu struck a chord with many of us right away,” said Bruce Betts, director of projects for the Planetary Society and a contest judge. “While there were many great entries, the similarity between the image of the heron and the TAGSAM arm of OSIRIS-REx was a clever choice. The parallel with asteroids as both bringers of life and as destructive forces in the solar system also created a great opportunity to teach.” For more information, visit osiris-rex.lpl.arizona.edu.



The public will be able to fly along with NASA's Voyager spacecraft as the twin probes head toward interstellar space, which is the space between stars. As indicated in this artist's concept, a regularly updated gauge using data from the two spacecraft will indicate the levels of particles that originate from far outside our solar system and those that originate from inside our solar bubble. Those are two of the three signs scientists expect to see in interstellar space. The other sign is a change in the direction of the magnetic field. Credit: NASA/JPL-Caltech.

NASA Invites the Public to Fly Along with Voyager

A gauge on the Voyager home page (voyager.jpl.nasa.gov) tracks levels of two of the three key signs scientists believe will appear when the spacecraft leave our solar neighborhood and enter interstellar space. When the three signs are verified, scientists will know that one of the Voyagers has hurtled beyond the magnetic bubble the Sun blows around itself, which is known as the heliosphere.

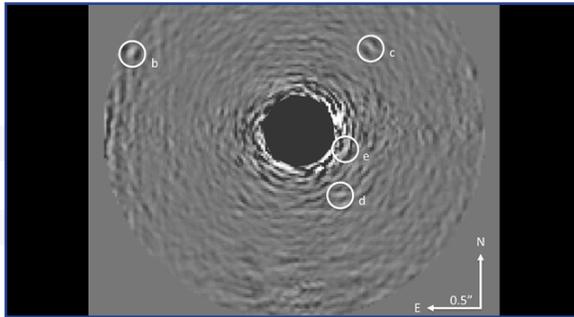
the direction of the magnetic field to confirm that the spacecraft has sailed beyond the breath of the solar wind and finally arrived into the vast cosmic ocean between stars. The direction of the magnetic field, however, requires periodic instrument calibrations and complicated analyses. These analyses typically take a few months to return after the charged particle data are received on Earth.

The gauge indicates the level of fast-moving charged particles, mainly protons, originating from far outside the heliosphere, and the level of slower-moving charged particles, also mainly protons, from inside the heliosphere. If the level of outside particles jumps dramatically and the level of inside particles drops precipitously, and these two levels hold steady, that means one of the spacecraft is closing in on the edge of interstellar space. These data are updated every six hours. Scientists then need only see a change in

Voyager 1, the most distant human-made spacecraft, appears to have reached this last region before interstellar space, which scientists have called “the magnetic highway.” Inside particles are zooming out and outside particles are zooming in. However, Voyager 1 has not yet seen a change in the direction of the magnetic field, so the consensus among the Voyager team is that it has not yet left the heliosphere. Voyager 2, the longest-operating spacecraft, but not as distant as Voyager 1, does not yet appear to have reached the magnetic highway, although it has recently seen some modest drops of the inside particle level.

NASA's Eyes on the Solar System program, a web-based, video-game-like tool to journey with NASA's spacecraft through the solar system, has added a Voyager module (1.usa.gov/13uYqGP) that takes viewers

along for a ride with Voyager 1 as it explores the outer limits of the heliosphere. Time has been sped up to show one day per second. Rolls and other maneuvers are incorporated into the program, based on actual spacecraft navigation data. The charged particle data are also shown.



This image shows the HR 8799 planets with starlight optically suppressed and data processing conducted to remove residual starlight. The star is at the center of the blackened circle in the image. The four spots indicated with the letters b through e are the planets. This is a composite image using 30 wavelengths of light and was obtained over a period of 1.25 hours on June 14 and 15, 2012. Credit: Project 1640.

Sifting Through the Atmospheres of Far-Off Worlds

Gone are the days of being able to count the number of known planets on your fingers. Today, there are more than 800 confirmed exoplanets — planets that orbit stars beyond our Sun — and more than 2700 other candidates. What are these exotic planets made of? Unfortunately, you cannot stack them in a jar like marbles and take a closer look. Instead, researchers are coming up with advanced techniques for probing the planets' makeup. One breakthrough to come in recent years is direct imaging of exoplanets. Groundbased telescopes have begun taking infrared pictures of the planets posing near their stars in family portraits. But to astronomers, a picture is worth even more than a thousand words if its light can be broken apart into a rainbow of different wavelengths.

Those wishes are coming true as researchers are beginning to install infrared cameras on groundbased telescopes equipped with spectrographs. Spectrographs are instruments that spread apart an object's light, revealing signatures of molecules. Project 1640, partly funded by NASA's Jet Propulsion Laboratory (JPL), recently accomplished this goal using the Palomar Observatory near San Diego. "In just one hour, we were able to get precise composition information about four planets around one overwhelmingly bright star," said Gautam Vasishth of JPL, co-author of a new study that appeared in the *Astrophysical Journal*. "The star is a hundred thousand times as bright as the planets, so we've developed ways to remove that starlight and isolate the extremely faint light of the planets." Along with groundbased infrared imaging, other strategies for combing through the atmospheres of giant planets are being actively pursued as well. For example, NASA's Spitzer and Hubble space telescopes monitor planets as they cross in front of their stars, and then disappear behind. NASA's upcoming James Webb Space Telescope will use a comparable strategy to study the atmospheres of planets only slightly larger than Earth.

In the new study, the researchers examined HR 8799, a large star orbited by at least four known giant, red planets. Three of the planets were among the first ever directly imaged around a star, thanks to observations from the Gemini and Keck telescopes on Mauna Kea, Hawaii, in 2008. The fourth planet, the closest to the star and the hardest to see, was revealed in images taken by the Keck telescope in 2010. Those images weren't enough, however, to reveal any information about the planets' chemical composition. That's where spectrographs are needed — to expose the "fingerprints" of molecules in a planet's atmosphere. Capturing a distant world's spectrum requires gathering even more planet light, and that means further blocking the glare of the star.

Project 1640 accomplished this with a collection of instruments, which the team installs on the groundbased telescopes each time they go on "observing runs." The instrument suite includes a coronagraph to mask out the starlight; an advanced adaptive optics system, which removes the blur of our moving atmosphere by making millions of tiny adjustments to two deformable telescope mirrors; an imaging spectrograph that records 30 images in a rainbow of infrared colors simultaneously; and a

state-of-the-art wave front sensor that further adjusts the mirrors to compensate for scattered starlight. “It’s like taking a single picture of the Empire State Building from an airplane that reveals a bump on the sidewalk next to it that is as high as an ant,” said Ben R. Oppenheimer, lead author of the new study and associate curator and chair of the Astrophysics Department at the American Museum of Natural History in New York.

Their results revealed that all four planets, although nearly the same in temperature, have different compositions. Some, unexpectedly, do not have methane in them, and there may be hints of ammonia or other compounds that would also be surprising. Further theoretical modeling will help to understand the chemistry of these planets. Meanwhile, the quest to obtain more and better spectra of exoplanets continues. Other researchers have used the Keck telescope and the Large Binocular Telescope near Tucson, Arizona, to study the emission of individual planets in the HR 8799 system. In addition to the HR 8799 system, only two others have yielded images of exoplanets. The next step is to find more planets ripe for giving up their chemical secrets. Several groundbased telescopes are being prepared for the hunt, including Keck, Gemini, Palomar, and Japan’s Subaru Telescope on Mauna Kea, Hawaii.

Ideally, researchers want to find young planets that still have enough heat left over from their formation, and thus more infrared light for the spectrographs to see. They also want to find planets located far from their stars, and out of the blinding starlight. NASA’s infrared Spitzer and Wide-field Infrared Survey Explorer (WISE) missions, and its ultraviolet Galaxy Evolution Explorer, now led by the California Institute of Technology (Caltech), have helped identify candidate young stars that may host planets meeting these criteria.

Still lower-mass planets, down to the size of Saturn, will be targets for imaging studies by the James Webb Space Telescope. “Rocky Earth-like planets are too small and close to their stars for the current technology, or even for James Webb to detect. The feat of cracking the chemical compositions of true Earth analogs will come from a future space mission such as the proposed Terrestrial Planet Finder,” said Charles Beichman, a co-author of the Project 1640 result and executive director of NASA’s Exoplanet Science Institute at Caltech. “The outer giant planets dictate the fate of rocky ones like Earth. Giant planets can migrate in toward a star, and in the process, tug the smaller, rocky planets around or even kick them out of the system. We’re looking at hot Jupiters before they migrate in, and hope to understand more about how and when they might influence the destiny of the rocky, inner planets,” said Vasishth. For more information, visit planetquest.jpl.nasa.gov.

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

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

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44th Lunar and Planetary Science Conference March 18-22, 2013, The Woodlands, Texas

The 44th Lunar and Planetary Science Conference (LPSC), held in March at The Woodlands Waterway Marriott Hotel and Convention Center in The Woodlands, Texas, was a huge success. In spite of the travel restrictions imposed by U.S. government sequester policies, a new record was set for number of attendees (1823); there were also a record number of abstracts submitted (2112). This year's meeting had an unprecedented number of student attendees, with students making up more than 31% of the total attendance, which illustrates that the LPSC is a meeting that is both accessible and important to young scientists.

LPSC, co-chaired by Stephen Mackwell of the Lunar and Planetary Institute and Eileen Stansberry and Dave Draper 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.

On Monday morning, the scientific sessions began. The conference featured five very full days of oral and poster sessions, featuring such topics as lunar remote sensing, early solar system chronology, planetary cartography, planetary dynamics and tectonics, volcanism, chondrites, isotopes, lunar samples, and much, much more. Special sessions included the latest results from the Mars Science Laboratory (MSL) and GRAIL missions; Vesta from the Inside Out; Vesta as the HED Parent Body; and Planetary Differentiation Across the Solar System. The complete program and abstracts are available at www.lpi.usra.edu/meetings/lpsc2013.



Participants enjoy greeting old friends and colleagues during the Sunday night welcome event.

The plenary session on Monday afternoon featured the Masursky Lecture by Lindy Elkins-Tanton of the Department of Terrestrial Magnetism at the Carnegie Institution for Science, entitled "On Building



Participants circulate among hundreds of posters during the poster session and exhibitor showcase.

Inc.). After their presentations on the current state of NASA's Science Mission Directorate and especially Planetary Sciences, they held a discussion period where they were able to interact with participants and answer questions from the audience.

Tuesday through Friday continued with two poster sessions and many more oral sessions, including more mission results. Other topics covered during the week included lunar achondrites, lunar samples, presolar grains, remotes sensing, chondrules, Mercury science from MESSENGER, and planetary atmospheres. The conference concluded on Friday afternoon.

An enhancement to this year's conference that was very popular among attendees was the introduction of LPSC Microbloggers. Limited bandwidth at the conference venue, combined with a sensitivity about interjecting distractions for speakers and the audience, has precluded Internet access in the oral sessions. The Microbloggers were a select group of participants that were given password-protected access to a dedicated WiFi network, allowing them to provide real-time reporting on the science being presented in the oral sessions. This coverage allowed participants to get a sense of what was going on in the sessions they were unable to attend. Another enhancement was the addition of e-posters, which allowed poster



During the Masursky Lecture, Lindy Elkins-Tanton discussed how magma ocean processes on planetesimals and planets control the earliest compositional differentiation and volatile content of the terrestrial planets.

an Earth-Like Planet." The session also recognized the recipients of the 2012 Dwornik Student Awards and the 2013 LPI Career Development Awards.

The NASA Headquarters Briefing on Monday evening was held in a non-typical fashion; because of the travel restrictions that were applied immediately before the conference, John Grunsfeld and Jim Green participated remotely via FaceTime (a videotelephony software application developed by Apple

presenters to upload a PDF file of their poster for viewing during and after the meeting. This addition received tremendous positive response from the attendees, as it is rather difficult to view hundreds of posters in a single evening.

Plans are already underway for the 45th LPSC, which will tentatively be held March 17–21, 2014. Mark your calendars! Meeting announcements and other details will be available at www.hou.usra.edu/meetings/lpsc2014/.

Meeting Highlights *continued . . .*



Winners and judges of the 2013 LPI Career Development Award, which is given to graduate students who are the first author of an abstract submitted to LPSC and selected for presentation.



John Grunsfeld and Jim Green of NASA Headquarters participated in the conference remotely using FaceTime.



Greg Schmidt (left), Julie Tygielski (center), and Joe Minafra (right) of the NLSI Center for Lunar Science and Exploration hosted a combined NLSI booth during the Exhibitor Showcase.

Spotlight on Education

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

Opportunities to Get Involved!

Host your own events this year! The upcoming launches of LADEE and MAVEN, as well as Comet ISON and InOMN events, provide opportunities for educator and public engagement around the broader topics of NASA lunar exploration, Mars exploration, planetary geology, and habitability!



LADEE Launch

NASA’s Lunar Atmosphere and Dust Environment Explorer (LADEE) Mission will launch between August 10 and October 13, 2013, into orbit around the Moon. LADEE provides a variety of exciting opportunities for students and the public to become directly involved in the mission. These activities range from those appropriate for kindergarten through 12th-grade students (K–12), to those appropriate for university and college students, as well as advanced amateur astronomers. For more information, visit www.nasa.gov/mission_pages/LADEE/main/get-involved.html.

Comet ISON

On November 28 of this year, Comet ISON might become one of the brightest comets ever seen! Just how bright the comet will become cannot yet be forecast reliably, but the planetary community should begin to plan possible events around this opportunity now.

International Observe the Moon Night (InOMN)

Saturday, October 12

This night will be dedicated to encouraging as many people as possible, worldwide, to spend an evening observing and learning about the Moon. A variety of resources are available at observethemoonnight.org.



MAVEN to Mars!

The Mars Atmosphere and Volatile Evolution Mission (MAVEN) is set to launch in November 2013! There is a variety of programs for educators, at lasp.colorado.edu/home/maven.

NASA is also inviting members of the public to submit their names and a personal message in the form of a haiku for a DVD to be carried onboard the MAVEN spacecraft. The DVD will carry every name submitted, but only three haikus will be selected. The deadline for all submissions is July 1, and an online public vote to determine the top three haikus will begin July 15. For more information, visit lasp.colorado.edu/maven/goingtomars.

Guidance for Education and Public Outreach Activities Under Sequestration

NASA has taken the first steps in addressing the mandatory spending cuts called for in the Budget Control Act of 2011. The law mandates a series of across-the-board spending reductions. As a result, NASA has implemented a number of new cost-saving measures, policies, and reviews. Additional information is available at www.nasa.gov/offices/education/about/sequestration-NASA-education-guidance.html.

Proposed FY14 NASA Budget Could Signify Changes for NASA STEM Education

The Administration's proposed FY14 budget could signify many changes for NASA's science, technology, engineering, and mathematics (STEM) education efforts. The President's proposed STEM Consolidation Initiative will consolidate 220 STEM programs that currently exist in 13 government agencies and reorganize the approach of federal agencies to STEM education.

In the Administration's proposed FY14 budget, NASA's overall education budget is reduced by \$49M (33%), and all education efforts are consolidated under NASA's Office of Education. Science Mission Directorate (SMD) education and outreach funds are eliminated; individual science mission budgets are reduced, reflecting elimination of education and outreach funds; and SMD is directed to no longer fund any education efforts. Further information can be found at smdepo.org.

The proposed NASA budget can be found at www.nasa.gov/news/budget/index.html. More information is available in the White House Office of Science and Technology Policy document, "Preparing a 21st Century Workforce, Science, Technology, Engineering, and Mathematics (STEM) Education in the 2014 Budget" (www.whitehouse.gov/sites/default/files/microsites/ostp/2014_R&Dbudget_STEM.pdf).



AAS Education Prize

The American Astronomical Society's Education Prize is to recognize outstanding contributions to the education of the public, students and/or the next generation of professional astronomers. Nominations are due by June 30. More information is available at aas.org/grants-and-prizes/prize-nominations.

2013 NASA EONS Solicitation

NASA's Office of Education is accepting new proposals under the Education Opportunities in NASA STEM (EONS) 2013 NASA Research Announcement. This is an umbrella announcement for opportunities under the Minority University Research and Education Program (MUREP), and includes calls for proposals in the following program elements for FY13–14: Tribal Colleges and Universities Experiential Learning Opportunities (TCU ELO) and NASA Innovations in Climate Education — Tribal (NICE-T). Proposals for both opportunities are due July 24, 2013.

For more information regarding these opportunities, please visit the NASA EONS page on the NSPIRES website at go.nasa.gov/14So8d6.

Astronomical Society of the Pacific 125th Annual Meeting

The Astronomical Society of the Pacific (ASP) celebrates the 125th gathering of educators and public outreach professionals at the 2013 annual meeting on July 20–24, 2013. This year’s meeting is hosted by San Jose State University, with a focus on STEM literacy across multiple disciplines. For more information and to register, visit bit.ly/WjEGVv.



ENSURING **STEM** LITERACY

125th Annual Meeting
Education & Public Outreach • Cosmos in the Classroom

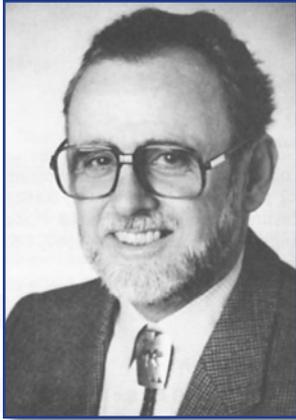
The conference is being held in conjunction with the Cosmos in the Classroom symposium (July 22–24), for college-level introductory astronomy instructors, graduate students, and post-docs.

ASP has announced that a limited number of scholarships are available for educators who wish to attend the Galileo Teacher Training Program (GTTP) workshop taking place as part of the ASP’s 125th Annual Meeting. The GTTP workshop (July 20–21) is for teachers in grades 3–12 and those who work with them; GTTP scholarships are for teachers in the state of California, and the deadline is June 24. For more information, visit astrosociety.org/education/asp-annual-meeting.

Lloyd V. Berkner Space Policy Internships

The goal of the Lloyd V. Berkner Space Policy Internship is to provide promising undergraduate and graduate students with the opportunity to work in the area of civil space research policy in the nation’s capital, under the aegis of the National Research Council’s Space Science Board. The autumn program is open to undergraduate and graduate students. The deadline for applications is June 7; selected candidates will be notified no later than July 5.

Additional information about the program, including the application procedure, can be found at sites.nationalacademies.org/SSB/sb_052239.



Peter Eberhardt, 1931-2013

Peter Eberhardt died in Switzerland on April 9, 2013, just shy of his 82nd birthday. Eberhardt spent most of his career at the Physikalisches Institut, University of Bern, Switzerland, but also held short-term positions in the United States, including at the University of Chicago and California Institute of Technology. He was an author or coauthor on numerous scientific publications, most of which involved noble gas analyses of lunar and meteoritic samples, but he also conducted research on several other elements and in other topical areas, especially that of comets. Eberhardt was a co-investigator on the early Apollo solar wind foil experiments, which exposed Al-foils to the solar wind on the lunar surface and analyzed the implanted solar wind in the Bern laboratory. He was an active participant in early lunar research on both regolith and rock samples.

Eberhardt received his Ph.D. in 1956. At the Physikalisches Institut he worked with the Institute's new director, Fritz Houtermans, and his young assistant, Johannes Geiss, who had both moved from Göttingen to Bern in 1954. In the framework of his Ph.D. work, Eberhardt built the first Bern mass spectrometer, called "Evelyne," which was followed by six more mass spectrometers built in house in Bern for isotopic analyses of noble gases.

Eberhardt moved to the United States for a short time, working with Harold Urey first in Chicago and then in La Jolla on systematic studies of the helium and neon isotopes in stony meteorites. While in the U.S. he met his soon-to-be wife Anita, then returned to Bern. In 1966 he was appointed to a distinguished chair position at the University of Bern. In 1976 he was offered a professorship at the University of California, and only by offering him a full professorship at Bern was the university successful in keeping him there.

Beginning in 1956, the research interests of the University of Bern were directed more and more toward space science. Under Eberhardt's guidance, new small and lightweight mass spectrometers were developed for use on rockets, and later on satellites. Another flagship instrument of the Institute, the "Berner Sonnenwindsegel," a collection device for solar wind, was flown on five Apollo lunar missions. Following that were projects in cometary research, and for the Giotto mission to Comet P/Halley he conceived a novel double-focusing mass spectrometer that was especially suited for that ambitious fast flyby mission, integrating that design in Giotto's highly successful Neutral Mass Spectrometer experiment. Eberhardt was also deeply involved in the development of the Rosina instrument onboard the current Rosetta mission to the Comet Churyumov-Gerasimenko, but sadly did not live to see the mission's arrival and science phase, which will take place next year.

Eberhardt particularly excelled in the field of experimental science. He was not only systematic and exact, but seemed to possess a sixth sense for lurking problems to emerge. If one of his students or another user made an error in the lab, it wouldn't be more than half a minute before Eberhardt suddenly appeared, asking if everything was all right. He just had an uncanny way of knowing what was going on. All the results appearing in his publications were exceptionally accurate and precise, and he held his students to these same standards. Whenever the power would go out in the lab — which was a major issue for the sensitive instruments — Eberhardt would storm into the lab like a commander on the field of battle and start calling out the security measures required, yet remaining calm and collected throughout the entire ordeal. Without Eberhardt, the precise and groundbreaking results for which Bern received an international reputation would never have been possible.

Eberhardt will be remembered not only for his outstanding achievements in the study of radiogenic, spallogenic, and solar-wind-implanted rare gases in meteorites, as well as the determination of the composition of the solar wind, but also as a sensitive and humorous man and scientist.



Pictured from left to right: Donald Yeomans, Peter Theisinger, and Peter Cook. Credit: NASA/JPL-Caltech.

Three from JPL on Time Magazine “Most Influential” List

On a new list of the 100 most influential people on Earth, three work at the same California address, where they’ve led projects to study things that are not on Earth. The list announced by TIME Magazine includes Don Yeomans, Pete Theisinger and Richard Cook, all at NASA’s Jet Propulsion Laboratory (JPL) in Pasadena, California. Yeomans manages NASA’s Near-Earth Objects Program Office at JPL, which coordinates the search for and tracking of asteroids and

comets passing into Earth’s neighborhood to identify possible hazards to Earth. Since 2004, Theisinger and Cook have alternated managing NASA’s Mars Science Laboratory project, which landed the highly successful car-sized Curiosity rover on Mars last summer. Both previously managed NASA’s Mars Exploration Rover project with its twin rovers, Spirit and Opportunity.

The TIME 100, as the magazine’s Managing Editor Richard Stengel has explained, is “a list of the most influential people in the world. They’re scientists, they’re thinkers, they’re philosophers, they’re leaders, they’re icons, they’re artists, they’re visionaries. People who are using their ideas, their visions, their actions to transform the world and have an effect on a multitude of people.” JPL Director Charles Elachi said, “We are honored to have three distinguished individuals from JPL on the TIME list of most influential people. Their contributions in the fields of asteroid research and Mars exploration is representative of all the exciting and important work being done at NASA and JPL on behalf of the American people.”

Yeomans graduated from Middlebury College in Vermont with a bachelor’s degree in mathematics and earned a doctorate in astronomy from the University of Maryland, College Park. He has worked at JPL since 1976. In addition to managing NASA’s Near-Earth Objects Program Office, Yeomans is supervisor for JPL’s Solar System Dynamics Group. He was a science team member for the Deep Impact/EPOXI mission, which deployed an impactor that was “run over” by Comet Tempel 1 in 2005 and flew close to Comet Hartley 2 in 2010. He was also the U.S. project scientist for the Japanese-led Hayabusa mission that returned a sample from near-Earth object Itokawa in 2010, and a team chief for the Near-Earth Asteroid Rendezvous mission that orbited, then landed on the asteroid Eros in 2001. The first images of the return of comet Halley in 1982 were also obtained based on Yeoman’s predictions.

Theisinger graduated from the California Institute of Technology in Pasadena with a degree in physics. His career at JPL began in 1967 with the Mariner 5 mission to Venus and now includes contributions to missions including the Voyager mission to the outer planets (launched in 1977 and still going) and the Galileo mission to Jupiter (launched in 1989 and concluded in 2003). His Mars experience dates back to the 1971 Mariner 9 orbiter mission to Mars.

Cook earned a bachelor’s degree in engineering physics from the University of Colorado, Boulder, and a master’s degree in aerospace engineering from the University of Texas, Austin. Cook joined JPL in 1989, working first on the Magellan mission to Venus. He was the Mars Pathfinder mission manager responsible for operating the first rover — Sojourner — on the surface of Mars in 1997. He held several roles on the Mars Exploration Rover project, which landed the Spirit and Opportunity rovers in 2004, including flight system manager and project manager.

The NASA Near Earth Objects (NEO) program at the agency's headquarters in Washington manages and funds the search, study, and monitoring of NEOs, or asteroids and comets, whose orbits periodically bring them close to Earth. NASA's study of NEOs provides important clues to understanding the origin of our solar system. NASA's Mars Science Laboratory project is using Curiosity to investigate the environmental history within Gale Crater, a location where the project has found that conditions were long ago favorable for microbial life. Curiosity, carrying 10 science instruments, landed in August 2012 to begin its two-year prime mission.

The TIME profile of Yeomans can be seen at time100.time.com/2013/04/18/time-100/slide/don-yeomans/. The profile of Theisinger and Cook can be seen at time100.time.com/2013/04/18/time-100/slide/peter-theisinger-and-richard-cook/. More information on the TIME 100 can be found at www.time.com/time100.

NASA Astrophysicist Elected to National Academy of Sciences



NASA astrophysicist Chryssa Kouveliotou, a senior scientist at NASA's Marshall Space Flight Center in Huntsville, Alabama, has been selected for membership in the National Academy of Sciences, in recognition of her distinguished and continuing achievements in original scientific research. Kouveliotou, a longtime leading researcher in NASA's space science mission, conducts extensive research on a host of astronomical phenomena including black holes, neutron stars, and gamma-ray bursts. She is one of 84 new members and 21 foreign associates from 14 countries recently announced as members.

Kouveliotou, who joined NASA in 2004, has been the principal investigator on numerous research projects in the United States and Europe. Currently, she is a co-investigator on the Gamma-ray Burst Monitor, an instrument flying onboard the Fermi Gamma-ray Space Telescope; an associated scientist on Swift, a multi-wavelength observatory dedicated to the study of gamma-ray burst science; and a member of the NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) science team, researching topics that investigate the most powerful explosions in the universe. Throughout her career, she has worked on a succession of vital NASA research missions, including the International Sun Earth Explorer-3, the Solar Maximum Mission, and the Burst and Transient Source Experiment, which flew on NASA's Compton Gamma-Ray Observatory.

Her numerous contributions to the fields of astronomy and astrophysics have expanded scientific understanding of fleeting, transient phenomena in the Milky Way galaxy and throughout the universe. Besides determining the unique properties of the highly energetic emissions from gamma-ray bursts — the brightest and most powerful cosmic events ever documented — Kouveliotou was part of the team that first revealed the extragalactic nature of these sources. She and her team made the first confirmed detection of ultra-dense neutron stars called magnetars, which are the cinders of stars left over after a supernova.

A native of Athens, Greece, Kouveliotou has received numerous awards for her work. In 2012 alone, she earned the Dannie Heineman Prize for Astrophysics and the NASA Exceptional Service Medal, and was named one of Time Magazine's 25 most influential people in space. For more information about Kouveliotou, visit go.nasa.gov/15ceDFJ.

NASA Selects 2013 Carl Sagan Fellows

NASA has selected five planet hunters to receive the 2013 Carl Sagan Exoplanet Postdoctoral Fellowships. The fellowship, named for the late astronomer, was created to inspire the next generation of explorers seeking to learn more about planets, and possibly life, around other stars. The primary goal of the fellowship program is to support outstanding recent postdoctoral scientists in conducting independent research related to the science goals of NASA's Exoplanet Exploration Program.



The 2013 Carl Sagan Fellows (left to right): Jared Males, University of Arizona, Tucson; Katja Poppenhaeger, Harvard Smithsonian Center for Astrophysics, Cambridge, Massachusetts; Jacob Simon, Southwest Research Institute, San Antonio, Texas; Jennifer Yee, California Institute of Technology, Pasadena, California; and Avi Shporer, Jet Propulsion Laboratory, Pasadena, California. Credit: NASA/JPL-Caltech.

Significant discoveries have already been made by previous Sagan Fellows. One recent discovery found that the size and location of an asteroid belt may determine whether complex life will evolve on an Earth-like planet. The program, created in 2008, awards selected postdoctoral scientists with annual stipends of \$65,500 for up to three years, plus an annual research budget of up to \$16,000.

The 2013 Sagan Fellows are Jared Males, who will work at the University of Arizona to investigate exoplanetary habitability by perfecting instrumentation to image Jupiter- and Saturn-sized planets in the liquid- water habitable zone of nearby stars; Katja Poppenhaeger, who will work at the Harvard Smithsonian Center for Astrophysics to explore how stars and close-in planets influence each other's evolution over time; Avi Shporer, who will work at NASA's Jet Propulsion Laboratory to find massive extrasolar planets that do not transit their parent stars; Jacob Simon, who will work at the Southwest Research Institute to understand the formation of planets out of gas and dust disks; and Jennifer Yee, who will work at the California Institute of Technology to measure the frequency of massive planets around low-mass stars using microlensing.

NASA has two other astrophysics theme-based fellowship programs: the Einstein Fellowship Program, which supports research into the physics of the cosmos, and the Hubble Fellowship Program, which supports research into cosmic origins. A full description of the 2013 fellows and their projects, and other information about these programs, is available at nexsci.caltech.edu/sagan/2013postdocRecipients.shtml.



Dan Johnston (left) and David Lehman (right). Credit: NASA/JPL-Caltech.

NASA Mars Orbiters Have New Project Managers

Two NASA spacecraft orbiting Mars, both working long past their original prime missions, have new project managers at NASA's Jet Propulsion Laboratory. Dan Johnston is the new project manager for NASA's Mars Reconnaissance Orbiter, and David Lehman is now project manager for NASA's Mars Odyssey.

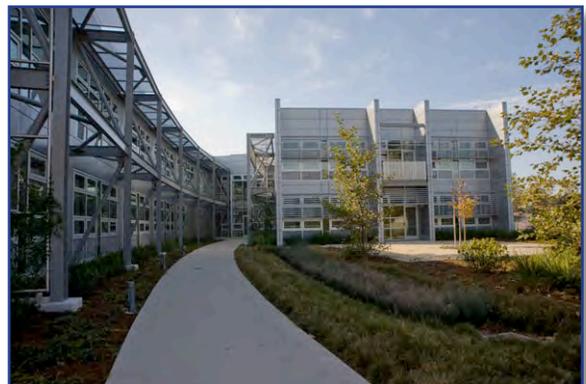
Johnston has worked on the Mars Reconnaissance Orbiter mission from its inception in 2000, through launch in 2005, and during operations in Mars orbit since 2006. He was the mission's design manager during development. Later roles have included mission manager and, since 2010, deputy project manager. Johnston earned a master's degree in aerospace engineering from the University of Texas, Austin; worked in private-industry support of NASA space shuttle mission operations; and joined JPL in 1989. The Mars Reconnaissance Orbiter has returned more data than all other Mars missions combined, observing Mars' surface, subsurface, and atmosphere in unprecedented detail and radically expanding our knowledge of the Red Planet.

Lehman managed NASA's twin-spacecraft Gravity Recovery and Interior Laboratory (GRAIL) Project from its inception in 2006 through the 2012 completion of its work orbiting Earth's moon. Lehman's career has taken him from undersea to deep space. Before joining JPL in 1980, he was a U.S. Navy submarine officer. At JPL, his accomplishments have included managing NASA's Deep Space 1 Project, which tested 12 innovative technologies, such as ion propulsion and autonomous navigation, on its way to an asteroid flyby. Lehman holds a master's degree in electrical engineering from Colorado State University, Fort Collins. Mars Odyssey has been orbiting the Red Planet since 2001, began systematic science observations there in early 2002, and broke the previous record for longest-working Mars spacecraft in December 2010. The mission's longevity enables continued science, including the monitoring of seasonal changes on Mars from year to year, in addition to communication-relay service for Mars rovers.

For more information about the Mars Reconnaissance Orbiter, visit www.nasa.gov/mro. For more about Mars Odyssey, visit mars.jpl.nasa.gov/odyssey.

NASA Ames Honored with 2013 Business Environmental Award

NASA's Ames Research Center recently was recognized for its exemplary sustainable business practices by one of San Francisco Bay Area's oldest and most prestigious environmental non-profits, Acterra: Action for a Healthy Planet. Ames received the 2013 Business Environmental Award in the category of "Sustainable Built Environment" for its high-performing Leadership in Energy and Environmental Design (LEED) platinum facility,



named Sustainability Base. The research center will be honored at the 2013 Business Environmental Awards Reception on Thursday, May 30, 2013, at Intuit Corporation, Mountain View, California.

“Sustainability Base is one of the most impressive buildings ever constructed,” said Steven Zornetzer, associate director for research and technology at Ames. “It is a showcase for our twin goals of providing a comfortable and desirable workplace for our staff, while advancing the science and art of managing intelligent buildings.” Active partnerships with academia, industry, and other government agencies have helped Ames progress toward these goals and contribute to its recognition for its “sustainable exemplary business practices,” according to Zornetzer.

Sustainability Base, completed last year, combines the natural, passive and “native to place” features of its location with forward-looking technologies to optimize energy efficiency and minimize resource consumption. The facility incorporates NASA technologies developed to support the agency’s missions in aeronautics and space exploration, by adapting and testing them in the built environment.

For more information about Sustainability Base, visit www.nasa.gov/sustainability-base.

NASA’s Johnson Space Center, White Sands Earn EPA “Green” Honors

Sustainable Materials Management



The U.S. Environmental Protection Agency (EPA) has recognized NASA’s White Sands Test Facility in Las Cruces, New Mexico, and Johnson Space Center in Houston, Texas, as Federal Green Challenge National Award winners. White Sands received the National Award for Overall Achievement for outstanding efforts in 2012 to advance sustainability efforts and its leadership in reducing the environmental footprint of federal government activities.

“In 2012, concrete and asphalt debris piles were safely recycled into 10,712 tons of reusable materials,” said Michael Jones, environmental project manager at White Sands. “As an alternative to purchasing new road base materials, WSTF now has reusable resources for future projects. This truly was a team effort between the White Sands facilities engineering, environmental, and safety organizations.”

Johnson was recognized for the highest progress over the previous year. The center increased municipal solid waste composted from 16 tons in 2011 to 250 tons in 2012, which represents a 1449% improvement. Johnson grounds contractor ProDyn EPES LLC of Annapolis, Maryland, is responsible for the compost pile. “Through our composting program, we no longer need to purchase mulch and compost, we don’t have to pay to get rid of yard debris, and we’re reducing greenhouse gas emissions — it’s a win-win situation all around,” said Michelle Fraser-Page, recycling manager at Johnson. “We’re thrilled to be recognized by the EPA for our efforts to increase sustainability.”

These achievements were made while participating in the Federal Green Challenge, a national effort under EPA’s Sustainable Materials Management Program. It challenges federal agencies to lead by example in reducing environmental impact. Federal agencies are recognized for outstanding efforts that

go beyond regulatory compliance and strive for annual improvements in selected areas. In 2012, about 300 federal facilities, representing 500,000 federal employees, reduced their environmental footprint in several target areas, resulting in an estimated combined cost savings of more than \$31 million.

For more information on sustainability efforts at NASA, visit www.nasa.gov/johnson.



NASA Mars Rover Mission Picked for Numerous Honors

NASA's Mars Science Laboratory Project has been selected to receive the top group honor from the Smithsonian's National Air and Space Museum — the Trophy for Current Achievement. The trophies for current and lifetime achievement are the National Air and Space Museum's most prestigious awards. They recognize outstanding achievements in the fields of aerospace science and technology and their history.

The Mars Science Laboratory Project built and operates the rover Curiosity, which has been investigating past and current environments in Mars' Gale Crater since its dramatic sky-crane landing in August of last year. The mission is using the Curiosity rover with its 10 science instruments to investigate whether an area within Gale Crater has ever offered an environment favorable for microbial life.

The Mars Science Laboratory Team was also recently honored with the Robert J. Collier Trophy, presented by the National Aeronautic Association, and the American Institute of Aeronautics and Astronautics Foundation Award. Two other teams from JPL that manage NASA spacecraft, the Dawn mission to the asteroid belt and the Voyager mission to interstellar space, were finalists for the 2012 Collier Trophy. "It's wonderful to see NASA's people and their accomplishments recognized by the aerospace community," NASA Administrator Charles Bolden said. "In particular, the Curiosity landing was the hardest NASA mission ever attempted in the history of robotic planetary exploration. These prestigious awards are a testament to the dedication and hard work of the entire worldwide team." For more about the mission, visit mars.jpl.nasa.gov/msl.

Mars Rover Social Media, JPL Website Win Webby Awards

NASA's Curiosity Mars rover social media and Solar System Exploration site have won four Webby Awards, the leading international honor for technical achievement and creativity online. Curiosity social media won both the judges' Webby Award and People's Voice for "Overall Social Presence." The Solar System Exploration website won the People's Voice in two categories: government and science.



The International Academy of Digital Arts and Sciences presents the Webby Awards. This year, the academy added categories for work in social Web; Curiosity's wins are two of the first in these categories. The Solar System Exploration site win in government keeps up a five-year streak for NASA in that category.

"NASA's Solar System Exploration site is the leading source of planet information, attracting 8 million unique visitors per year," said Alice Wessen, the manager of the website from NASA's Jet Propulsion Laboratory. "Many of our 30 million annual page views are from students seeking information on the planets for their schoolwork. We even have a section dedicated to homework help."

Visiting a NASA website is just one way to get information from the agency. "We also engage the public in the social networks where they spend the most time," said Veronica McGregor, JPL's news manager and lead for the Curiosity social media campaign. "Through Facebook, Twitter, and Reddit, we speak with millions. The public was invited to watch the rover's construction, launch, landing, and news briefings live on Ustream.tv, and participate in real-time chats with each other and mission experts.

Other NASA sites commended by the Webby Awards this year include NASA's main website (www.nasa.gov), an honoree in government; JPL's Space Images (www.jpl.nasa.gov/spaceimages), a nominee in government; and NASA's "Eyes on the Earth" (eyes.jpl.nasa.gov/earth), an honoree in science. Members of The International Academy of Digital Arts and Sciences select winners for the Webby Awards. A popular vote conducted online determines the winners of the People's Voice Awards. For more information about the Webby Awards, visit www.webbyawards.com.

NASA Awards Cooperative Agreement for Internships



NASA's Office of Education has awarded a cooperative agreement to the Universities Space Research Association (USRA) to support the agency's education internship programs. The award's value is estimated at between \$3 million and \$10 million per year, depending on options. The period of performance will not exceed five years.

The agreement covers NASA's Minority University Research and Education Program (MUREP) and the Space Grant Program, which provide internship opportunities to qualified STEM students and educators. This agreement may include support to the National Science Foundation, which implements other internship programs throughout the federal government, as outlined in the president's budget request for fiscal year 2014.

USRA is a recognized leader in administering educational opportunities for students and teachers that lead to employment with NASA and the broader aerospace industry requiring science, technology, engineering, and mathematics (STEM) expertise. For more information about USRA, visit www.usra.edu. To learn about internship opportunities at NASA, visit intern.nasa.gov.

NASA Invests in Small Business Innovative Research and Technology Proposals to Enable Future Missions

NASA has selected 295 research and technology proposals from 216 American small businesses for negotiations that may lead to contract awards worth a combined \$38.7 million. The proposals are part of NASA's Small Business Innovation Research Program (SBIR) and Small Business Technology Transfer (STTR) Program. SBIR addresses specific technology gaps in agency missions while striving to complement other agency research investments. Numerous NASA efforts, including modern air traffic control systems, Earth-observing spacecraft, human spaceflight and the International Space Station, and NASA's Mars rovers have benefited from the program. The STTR program additionally facilitates the transfer of technology developed by a research institution through the entrepreneurship of a small business.



“NASA’s small business innovation research projects are strong and valuable investments that continue to pay dividends to NASA and the American people,” said Michael Gazarik, NASA’s associate administrator for space technology in Washington. “If successful, these early-stage technology concepts will mature to meet NASA’s mission needs while also providing solutions that have wide applicability in the marketplace, potentially becoming new products, services, and jobs here in the U.S.”

Innovative research areas among these selected proposals include new technologies to reduce drag on aircraft and thereby increase fuel efficiency during supersonic flight; improved advanced spacesuit life support systems; development of innovative fixed-wing unmanned aerial vehicles offering unique capabilities for Earth science research and environmental monitoring; innovative concepts and technologies to enable significant increases in the capacity and efficiency of air transportation systems, potentially aiding in on-time arrival, departure, and taxiing of airplanes while reducing their fuel consumption, noise, and pollution; creating a launch system that provides low-cost, reliable, on-demand, routine space access for small satellites, weighing up to about 44 pounds; and developing a rugged laser transmitter for new detection systems to profile Earth’s atmospheric ozone.

Selection criteria included technical merit and feasibility, along with experience, qualifications, and facilities. Additional criteria included effectiveness of the work plan and commercial potential and feasibility. NASA’s Ames Research Center manages the SBIR program for NASA’s Space Technology Mission Directorate. NASA’s 10 field centers manage individual projects. For more information about NASA’s SBIR program and a list of selected companies, visit sbir.nasa.gov.

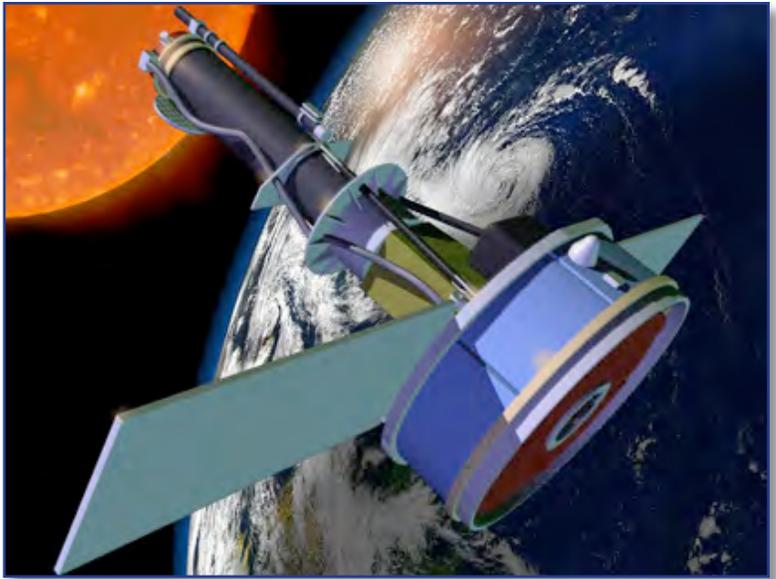
NASA Selects Explorer Projects to Probe Earth’s Upper Atmosphere

NASA has selected a new satellite mission and a new space-based instrument to begin development as part of the agency’s Heliophysics Explorer Program. The projects will provide space observations to study Earth’s ionosphere and thermosphere.

The Ionospheric Connection (ICON) mission, led by Thomas Immel of the University of California, Berkeley, will probe the extreme variability of Earth’s ionosphere with in situ and remote-sensing instruments. Fluctuations in the ionosphere interfere with signals from communications and global positioning satellites, which can have an economic impact on the nation. The Global-scale Observations of the Limb and Disk (GOLD) mission of opportunity, led by Richard Eastes of the University of

Central Florida in Orlando, is an imaging instrument that will fly on a commercial communications satellite in geostationary orbit to image the Earth's thermosphere and ionosphere.

"One of the frontier areas of heliophysics is the study of the interface between outer space and the upper reaches of Earth's atmosphere," said John Grunsfeld, NASA associate administrator for science at NASA Headquarters, Washington. "These selected projects use innovative solutions to advance our knowledge of this relatively unexplored region. The two missions together will result in significantly more advances in our understanding of Earth's atmosphere and ionosphere than either would alone."



These two Explorer projects were selected from proposals submitted in response to the NASA Explorer announcement of opportunity in 2010. The proposals were judged to offer the best science value and feasible development plans among the six concept studies submitted to NASA in September 2012. Costs for NASA Explorer missions, such as ICON, are capped at \$200 million each (fiscal year 2011 dollars), excluding the launch vehicle. Explorer missions of opportunity, such as GOLD, are capped at \$55 million each. The new missions are expected to launch in 2017.

NASA also announced the selection of two other Explorer missions for formulation: a planet-hunting satellite and an International Space Station instrument to observe X-rays from stars. The Transiting Exoplanet Survey Satellite (TESS) and Neutron Star Interior Composition Explorer (NICER) were among four concept studies submitted in September 2012. NASA determined these two offer the best scientific value and most feasible development plans.

TESS will use an array of telescopes to perform an all-sky survey to discover transiting exoplanets ranging from Earth-sized to gas giants, in orbit around the nearest and brightest stars in the sky. Its goal is to identify terrestrial planets in the habitable zones of nearby stars. Its principal investigator is George Ricker of the Massachusetts Institute of Technology in Cambridge. NICER will be mounted on the space station and measure the variability of cosmic X-ray sources, a process called X-ray timing, to explore the exotic states of matter within neutron stars and reveal their interior and surface compositions. The principal investigator for NICER is Keith Gendreau of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

The Explorer program is the agency's oldest continuous program. It is designed to provide frequent, low-cost access to space for principal investigator-led space science investigations relevant to the heliophysics and astrophysics programs in NASA's Science Mission Directorate in Washington. The Explorer program has launched more than 90 missions since 1958, including Explorer 1, which discovered Earth's radiation belts, and the Nobel Prize-enabling mission Cosmic Background Explorer (COBE) mission. For more information about the Explorer program, visit explorers.gsfc.nasa.gov.

NASA Successfully Launches Three Smartphone Satellites



Three smartphones destined to become low-cost satellites rode to space Sunday onboard the maiden flight of Orbital Science Corporation's Antares rocket from NASA's Wallops Island Flight Facility in Virginia. The trio of "PhoneSats" is operating in orbit, and may prove to be the lowest-cost satellites ever flown in space. The goal of NASA's PhoneSat

mission is to determine whether a consumer-grade smartphone can be used as the main flight avionics of a capable, yet very inexpensive, satellite.

Transmissions from all three PhoneSats have been received at multiple ground stations on Earth, indicating they are operating normally. The PhoneSat team at NASA's Ames Research Center continued to monitor the satellites in the days following the launch. The satellites were expected to remain in orbit for as long as two weeks.

"It's always great to see a space technology mission make it to orbit — the high frontier is the ultimate testing ground for new and innovative space technologies of the future," said Michael Gazarik, NASA's associate administrator for space technology in Washington. "Smartphones offer a wealth of potential capabilities for flying small, low-cost, powerful satellites for atmospheric or Earth science, communications, or other space-born applications. They also may open space to a whole new generation of commercial, academic and citizen-space users."

Satellites consisting mainly of the smartphones sent information about their health via radio back to Earth in an effort to demonstrate they can work as satellites in space. The spacecraft also took pictures of Earth using their cameras. Amateur radio operators around the world were able to participate in the mission by monitoring transmissions and retrieving image data from the three satellites. Large images were transmitted in small chunks and reconstructed through a distributed ground station network.

NASA's off-the-shelf PhoneSats already have many of the systems needed for a satellite, including fast processors, versatile operating systems, multiple miniature sensors, high-resolution cameras, GPS receivers, and several radios. NASA engineers kept the total cost of the components for the three prototype satellites in the PhoneSat project between \$3500 and \$7000 by using primarily commercial hardware and keeping the design and mission objectives to a minimum. The hardware for this mission is the Google-HTC Nexus One smartphone running the Android operating system.

NASA added items a satellite needs that the smartphones did not have — a larger, external lithium-ion battery bank and a more powerful radio for messages it sent from space. The smartphone's ability to send and receive calls and text messages was disabled. Each smartphone was housed in a standard cubesat structure, measuring about 4" square. The smartphone acted as the satellite's onboard computer. Its sensors were used for attitude determination and its camera for Earth observation. More information can be found at www.phonesat.org.

The PhoneSat project is a technology demonstration mission conceived at Ames and funded by NASA's Space Technology Mission Directorate at NASA Headquarters. The PhoneSat family of systems is part of an overall NASA Ames effort to assess commercial grade technologies for use in small- and nano-spacecraft systems to save development costs and leverage industry investments in high-quality, mass-produced components. Ames has successfully completed and delivered eight nanosatellites for launch since 2006. For more about information about NASA's Small Spacecraft Technology Program and the PhoneSat mission, visit www.nasa.gov/smallsats.

BOOKS



Meteorites: Witnesses of the Origin of the Solar System.

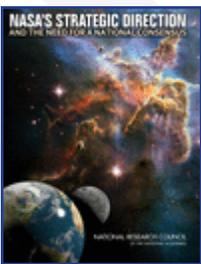
By Franz Brandstätter, Ludovic Ferrière, and Christian Köberl. Edition Lammerhuber, 2013. 272 pp., Hardcover, \$50.00. www.edition.lammerhuber.at

Stones that fall from the sky have been known for centuries. But only during the last 200 years could their extraterrestrial origin be confirmed. Today scientists know that meteorites are the only witnesses of the formation of the solar system (and Earth) that are available to us. Their composition provides valuable information about the origin of the chemical elements, as well as how and when our planetary system was created. This book gives an overview of the history of the study of meteorites and how to identify their classification and composition, including the exciting history of meteorites from the Moon and Mars. Almost 300 color images illustrate the historical context of these fascinating objects, and their stories give a unique insight into the largest meteorite collection of the world — the collection in the natural history museum in Vienna.

Forever Young: A Life of Adventure in Air and Space.

By John W. Young and James R. Hansen. University Press of Florida, 2012. 432 pp., Hardcover, \$29.95. upf.com

He walked on the Moon. He flew six space missions in three different programs — more than any other human. He served with NASA for more than four decades. His peers called him the “astronaut’s astronaut.” Enthusiasts of space exploration have long waited for John Young to tell the story of his two Gemini flights, his two Apollo missions, the first-ever space shuttle flight, and the first Spacelab mission. *Forever Young* delivers all that and more: Young’s personal journey from engineering graduate to fighter pilot, to test pilot, to astronaut, to high NASA official, to clear-headed predictor of the fate of planet Earth. Young, with the assistance of aerospace historian James Hansen, recounts the great episodes of his amazing flying career in fascinating detail and with wry humor. He portrays astronauts as ordinary human beings and NASA as an institution with the same ups and downs as other major bureaucracies. He discusses the risks of space travel, including what went wrong with the Challenger and Columbia shuttles. *Forever Young* is one of the last memoirs produced by an early American astronaut and the first memoir written by a chief of the NASA astronaut corps. Young’s experiences and candor make this book indispensable to everyone interested in the U.S. space program.



NASA's Strategic Direction and the Need for a National Consensus.

By the Committee on NASA's Strategic Direction; Division on Engineering and Physical Sciences; National Research Council. National Academies Press, 2012. 67 pp., Paperback, \$35.00. www.nap.edu

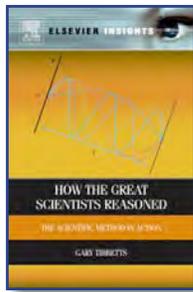
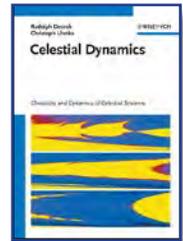
NASA is widely admired for its astonishing accomplishments since its formation in 1958. Looking ahead, what can the nation and the world expect of NASA? What will be the agency’s goals and objectives, and what will be the strategy for achieving them? How will the goals, objectives, and strategies be established and by whom? How will they be modified to reflect changes in science, technology, national priorities, and available resources? In late 2011, the U.S. Congress directed the NASA Office of Inspector General to commission a “comprehensive independent assessment of NASA’s strategic direction and agency management.” Subsequently, NASA requested that the National Research Council (NRC) conduct

this independent assessment. In the spring of 2012, the NRC Committee on NASA's Strategic Direction was formed and began work on its task. The committee determined that only with a national consensus on the agency's future strategic direction — along the lines described in the full NRC report — can NASA continue to deliver the wonder, knowledge, national security, economic benefits, and technology that have been typified by its earlier history. This report summarizes the findings and recommendations of the committee. This report is also available as a free full-text download from the National Academies Press website.

Celestial Dynamics: Chaoticity and Dynamics of Celestial Systems.

By Rudolph Dvorak and Christoph Lhotka. Wiley, 2013, 320 pp., Hardcover, \$140.00. www.wiley.com

Written by an internationally renowned expert author and researcher, this monograph fills the need for a book conveying the sophisticated tools needed to calculate exoplanet motion and interplanetary space flight. It is unique in considering the critical problems of dynamics and stability, making use of the software *Mathematica*, including supplements for practical use of the formulae. This book is a must-have for astronomers and applied mathematicians alike.



How the Great Scientists Reasoned: The Scientific Method in Action.

By Gary Tibbetts. Elsevier, 2012, 176 pp., Hardcover, \$74.95. www.elsevier.com

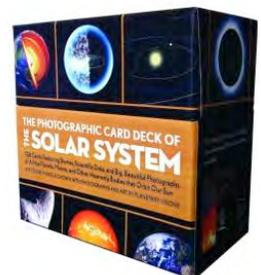
This book teaches the basic modes of scientific thought, not by philosophical generalizations, but by illustrating in detail how great scientists from across the sciences solved problems using scientific reason. Examples of these scientists include Christopher Columbus, Joseph Priestly, Antoine Lavoisier, Michael Faraday, Wilhelm Röntgen, Max Planck, Albert Einstein, and Niels Bohr. Written by a successful research physicist who has engaged in many studies and years of research, all in the attempt to extract the secrets of nature, this book captures the excitement and joy of research. The process of scientific discovery can be a roller coaster ride of despairing valleys and exhilarating highs. This book sketches the powerful reasoning that led to many different discoveries, but also celebrates the “ah-ha” moments experienced by each scientist, letting readers share the thrilling instant when each scientist reached the critical revelation in his research.

EDUCATIONAL RESOURCE

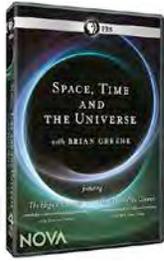
The Photographic Card Deck of the Solar System.

By Marcus Chown. Black Dog & Leventhal, 2012. 126 cards, \$24.95. www.workman.com

This beautiful photographic card deck includes 126 cards, 5" × 5", each covering a single topic, such as an individual planet or moon, asteroids, comets, gravity, the movement of the planets, solar wind, dwarf planets, dark matter, the possibility of life elsewhere, famous astronomers, and more. The front side of each card features a full-sized photograph, and the back includes explanatory text and key scientific data illustrating the most important and interesting aspects of each topic. The cards are perfect for students, but they also make an excellent gift for scientists and adults who are fascinated by the beauty and complexity of space.



DVD



Space, Time, and the Universe with Brian Greene.

Produced by PBS, 2012, four discs. \$34.99. www.shoppbs.org

Host Brian Greene, professor of physics and mathematics at Columbia University and best-selling author, takes viewers on an exciting and in-depth exploration of a groundbreaking new theory: one of the most ambitious and exciting scientific theories ever posed, and one that may be the long-sought “Theory of Everything.” This DVD set features “The Elegant Universe” and “The Fabric of the Cosmos.”

Ultimate Mars Challenge.

Produced by PBS, 2012, one disc. \$24.99. www.shoppbs.org

In August 2012, a rover named Curiosity touched down inside Mars’ Gale Crater, carrying 10 new instruments designed to look for signs that Mars might have once been suitable for life. The mission was risky — after parachuting through the martian atmosphere at twice the speed of sound, Curiosity was successfully lowered to the planet’s surface by a “sky crane.” With inside access to the massive team of scientists and engineers responsible for Curiosity’s on-the-ground experiments, NOVA was there for the exhilarating moments after Curiosity’s landing. Curiosity has joined the team that includes the Mars Odyssey, Express, and Reconnaissance orbiters, along with the tireless Opportunity rover. As a dynamic new picture of Mars is revealed, we’ll discover answers to the questions raised by 40 years of roving Mars: How do we define life? How does life begin and what does it need to survive? Are we alone in the universe?



FOR KIDS!!!



Spacecraft Models.

Available from Papa Foxtrot. \$32.00. papafoxtrot.com

London-based toymaker Papafoxtrot has created a series of 4" scale models of the Dragon, Spektr-R, ORS-1, GEOTAIL, and Cygnus spacecraft. These detailed models are made of wood and aluminum, and make great desk ornaments!

Space Chess.

Available from the JPL Store, \$25.00. caltechstore.caltech.edu/JPLLAB/

This chess game is great for any space enthusiast. Rooks are space shuttles, knights are the Moon, and bishops are Saturn. The kings and queens are represented by Earth and Mars. An attractive box holds a 14" × 14" playing board, solid plastic pieces that are 2" to 3" tall, and rules. For ages 6 and up.





National Geographic Space Exploration Kit.

Produced by National Geographic. \$34.95.

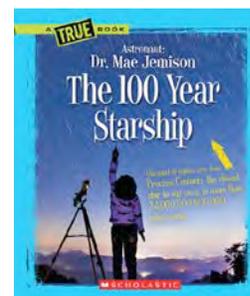
shop.nationalgeographic.com

Blast off on a mission to explore outer space and the objects in it with a wide array of cosmic experiments. Launch three types of rockets using balloons and chemical reactions to learn about rocket propulsion. Build a telescope and star map to investigate the stars and constellations. Assemble a model of the solar system and learn about its planets. Find out about day and night, seasons, and lunar phases. Investigate how meteorites

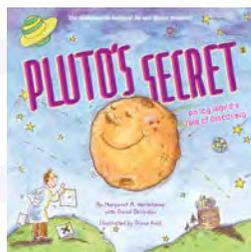
formed the craters on the Moon. Build a sundial and a solar collector to experiment with the Sun. Grasp a comet's tail and learn how meteoroids become falling stars. See how the universe is expanding with a simple model. A full-color, 48-page experiment book is included to guide your exploration. For ages 8 and up.

A True Book Series — Dr. Mae Jemison and 100 Year Starship.

By Mae Jemison and Dana Meachen Rau. Children's Press, 2013. Set of four hardcover books, 48 pp. each, \$116.00. www.scholastic.com



During her long and storied career, Dr. Mae Jemison has worked as a medical doctor, a technology researcher, an educator, and an astronaut. In 1992, she made history by spending eight days in Earth's orbit, making her the first black woman ever to visit space. Twenty years later, Dr. Jemison has begun a new initiative to push space travel further than ever before by making a goal of reaching outside our solar system to another star within the next 100 years. In this exciting new True Book series, readers will join Jemison as she guides them on a tour of our solar system and explains how astronomers have used technology to discover new stars and planets. The four books in this series are *Discovering New Planets*, *Exploring Our Sun*, *Journey Through Our Solar System*, and *The 100 Year Starship*, and can be purchased separately. For grades 3–5.



Pluto's Secret: An Icy World's Tale of Discovery.

By Margaret A. Weitekamp and David DeVorkin. Abrams Books for Young Readers, 2013. 40 pp., Hardcover, \$16.95. www.abramsbooks.com/abramsyoungreaders.html

People, especially children, have been baffled, bewildered, and even outraged by the fact that Pluto is no longer called a planet. Through whimsical artwork and an entertaining dialogue format, *Pluto's Secret* explains the true story of this distant world. Providing a history of the small, icy world from its discovery and naming to its recent reclassification, this book presents a fascinating look at how scientists organize and classify our solar system as they gain new insights into how it works and what types of things exist within it. The book includes a glossary and bibliography. For ages 5 and up.

June

- 2–6 **222nd Meeting of the American Astronomical Society**, Indianapolis, Indiana. <https://aas.org/meetings/aas222>
- 2–7 **Exploring the Formation and Evolution of Planetary Systems**, Victoria, Canada. <http://www.iau.org/science/meetings/future/symposia/1064/>
- 3–4 **First Annual International Conference on Astronomy and Astrophysics (Astro 2013)**, Singapore. <http://www.astro-conf.org/>
- 3–5 **Next-Generation Suborbital Researchers Conference 2013**, Broomfield, Colorado. <http://nsrc.swri.org>
- 6–9 **First International Workshop on Education in Astrobiology**, Hoor, Sweden. <http://www.nordicastrobiology.net/IWEA/>
- 10–14 **International Venus Workshop**, Catania, Italy. <http://www.iaps.inaf.it/Venus2013/>
- 10–14 **AbGradCon 2013**, Montreal, Canada. <http://www.abgradcon.org>
- 11–14 **Isotopes as Diagnostic Tools in Astronomy, Geology and Biology**, Hoor, Sweden. <http://www.nordicastrobiology.net/Isotopes2013/>
- 15–16 **IPPW-10 Short Course on Entry, Descent, and Landing Systems**, San Jose, California. <http://www.ippw10.com/index.php/program/short>
- 15–19 **11th International GeoRaman Conference**, St. Louis, Missouri. <http://georaman2014.wustl.edu>
- 17–21 **10th International Planetary Probe Workshop (IPPW-10)**, San Jose, California. <http://ippw10.com/>
- 17–21 **14th International Conference on Electromagnetic and Light Scattering (ELS-XIV)**, Lille, France. <http://www-loa.univ-lille1.fr/ELS-XIV>
- 18–20 **10th IAA Low-Cost Planetary Missions Conference (LCPM-10)**, Pasadena, California. <http://lcpm10.caltech.edu/>
- 18–21 **From Exoplanets to Distant Galaxies: SPICA's New Window on the Cool Universe**, Kanagawa, Japan. <http://www.ir.isas.jaxa.jp/SPICA/spica2013/>
- 20–21 **Interplanetary Small Satellite Conference**, Pasadena, California. <http://www.intersmallsatconference.org/>

- 23–25 **2013 Space Cryogenics Workshop**, Girdwood, Alaska. www.spacecryogenicsworkshop.org
- 23–28 **Gordon Conference on Origins of Solar Systems**, South Hadley, Massachusetts. <http://www.grc.org/programs.aspx?year=2013&program=origins>
- 24–27 **8th Workshop on Catastrophic Disruption in the Solar System (CD8)**, Hapuna Beach, Hawaii. <http://www.cd8.hawaii-conference.com/>
- 24–27 **Herschel Data Processing for Newcomers**, Villanueva de la Canada, Spain. <http://herschel.esac.esa.int/DPforNewcomers2013.shtml>
- 24–28 **10th Annual Meeting of the Asia Oceania Geosciences Society (AOGS)**, Brisbane, Australia. <http://www.asiaoceania.org/aogs2013/public.asp?page=home.htm>
- 24–28 **Crossing the Boundaries in Planetary Atmospheres: From Earth to Exoplanets**, Annapolis, Maryland. <http://chapman.agu.org/planetaryatmospheres/>
- 25–28 **5th Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS)**, Gainesville, Florida. http://core.ieee-whispers.com/index.php?option=com_content&view=article&id=211&Itemid=55
- 25–July 2 **Summer Course “Molecules in Space,”** Onsala, Sweden. <http://www.nordicastrobiology.net/Onsala2013>
- 30–July 2 **3rd Workshop on Binaries in the Solar System**, Kohala Coast, Hawaii. <http://www.boulder.swri.edu/binaries3-mtg/>
- 30–Jul 2 **Australian Astrobiology Meeting**, Sydney, Australia. <http://astrobiologyaustralia.com.au>

July

- 1–4 **International Symposium on Planetary Sciences (IAPS2013)**, Shanghai, China. <http://202.127.29.4/meetings/iaps2013>
- 8–12 **Magnetospheres of the Outer Planets 2013**, Athens, Greece. <http://space.academyofathens.gr/mop2013/>
- 8–13 **European Week of Astronomy and Space Science**, Turku, Finland. <http://www.astro.utu.fi/EWASS2013/index.php>
- 9–11 **Ninth Meeting of the Small Bodies Assessment Group**, Pasadena, California. <http://www.lpi.usra.edu/sbag/meetings/>

- 9–11 **Comets as Tracers of Solar System Formation and Evolution**, Toulouse, France. <http://icw.space.swri.edu/index.htm>
- 12 **Rocks in our Solar System – Bridging the Gap Between Meteor, Meteorite and Asteroid Studies**, Turku, Finland. <http://www.physics.helsinki.fi/conf/EWASS2013>
- 13–14 **LunGradCon 2013**, Virtual Meeting. <http://lasp.colorado.edu/ccldas/lgc2013>
- 15–20 **Protostars and Planets VI**, Heidelberg, Germany. <http://www.ppvi.org>
- 16–18 **NASA Lunar Science Forum**, Virtual Meeting. <http://lunarscience.nasa.gov/lsf2013>
- 17–19 **Dusty Visions 2013**, Stuttgart, Germany. <http://www.dsi.uni-stuttgart.de/cosmicdust/news/dustyvisions2013.html>
- 22–26 **The Pluto System on the Eve of Exploration by New Horizons: Perspectives and Predictions**, Columbia, Maryland. <https://dnnpro.ouster.jhuapl.edu/plutoscience/Home.aspx>
- 22–Aug 9 **The University of California International Summer School on AstroComputing 2013: Star and Planet Formation**, Santa Cruz, California. <http://hipacc.ucsc.edu/ISSAC2013.html>
- 29–31 **PLATO 2.0 Science Workshop**, Noordwijk, The Netherlands. <http://www.sciops.esa.int/index.php?project=CONF2013&page=PLATO2013>
- 29–Aug 2 **76th Annual Meeting of the Meteoritical Society**, Edmonton, Canada. <http://metsoc2013edmonton.org/>

August

- 4–8 **Large Meteorite Impacts and Planetary Evolution V**, Sudbury, Ontario, Canada. <http://www.hou.usra.edu/meetings/sudbury2013>
- 5–9 **The 6th Meeting on Cosmic Dust**, Kobe, Japan. <https://www.cps-jp.org/~dust/Welcome.html>
- 14–16 **4th Planetary Crater Consortium Meeting**, Flagstaff, Arizona. <http://www.planetarycraterconsortium.nau.edu>
- 14–16 **International Conference on Astronomy and Cosmology**, Chicago-North Shore, Illinois. <http://www.omicsgroup.com/conferences/astronomy-cosmology-2013/>
- 16–25 **Summer Course: “Impacts and their Role in the Evolution of Life,”** Kuressaare, Estonia. <http://www.nordicastrobiology.net/Impacts2013/>

- 19–22 **The Annual Conference on Characterization and Radiometric Calibration for Remote Sensing**, Logan, Utah. <http://www.calcon.sdl.usu.edu/>
- 25–30 **Goldschmidt 2013 Conference**, Florence, Italy. <http://goldschmidt.info/2013/>
- 26–30 **Exploiting the Herschel Science Archive: A Data Processing Workshop**, Pasadena, California. <https://nhscsci.ipac.caltech.edu/sc/index.php/Workshops/ArchiveDPAug2013>
- 26–30 **Meteoroids 2013**, Poznan, Poland. <http://www.astro.amu.edu.pl/Meteoroids2013/index.php>

September

- 9–12 **The 11th Hellenic Astronomical Conference**, Athens, Greece. <http://www.helas.gr/conf/2013/index.php>
- 9–12 **LSST @ Europe: The Path to Science**, Cambridge, United Kingdom. <http://www.lsstcorp.org/meetings/lsst-europe-2013/>
- 9–13 **European Planetary Science Conference (EPSC 2013)**, London, United Kingdom. <http://www.epsc2013.eu>
- 10–12 **Planet Formation and Evolution 2014**, Kiel, Germany. <http://www1.astrophysik.uni-kiel.de/~kiel2014/main/>
- 23–24 **Origin of the Moon**, London, United Kingdom. <http://royalsociety.org/events/2013/origin-moon/>
- 24–28 **Second International Congress of Astrobiology in Columbia**, Medellín, Columbia. <http://www.astrobiologia.org/2-congreso-internacional-de-astrobiologia.html>
- 25–26 **Origin of the Moon – Challenges and Prospects**, Chicheley, United Kingdom. <http://royalsociety.org/events/2013/moon-origin-satellite/>

October

- 3–4 **Workshop on Golden Spike Lunar Human Expeditions: Opportunities for Intensive Lunar Scientific Exploration**, Houston, Texas. <http://www.hou.usra.edu/meetings/gs2013/>
- 6–11 **45th Meeting of the American Astronomical Society Division for Planetary Sciences (DPS 2013)**, Denver, Colorado. <http://aas.org/meetings/45th-meeting-division-planetary-sciences>
- 7–11 **Third Workshop on Robotic Autonomous Observatories**, Torremolinos, Spain. <http://astrorob.iaa.es/>

Calendar *continued* . . .

- 7–11 **ESO/NUVA/IAG Workshop on Challenges in UV Astronomy**, Garching, Germany. <http://www.eso.org/sci/meetings/2013/UVAstro2013/rationale.html>
- 14–16 **Annual Meeting of the Lunar Exploration Analysis Group**, Laurel, Maryland. <http://www.hou.usra.edu/meetings/leag2013/>
- 14–18 **Fourth Moscow international Solar System Symposium (4M-S3)**, Moscow, Russia. <http://ms2013.cosmos.ru/>
- 15–18 **The (F)IR Universe Three Years Later – The Contributions by Herschel**, Noordwijk, The Netherlands. http://herschel.esac.esa.int/The_FIR_Universe.shtml
- 20–25 **Planet Mars 4**, Les Houches, France. <http://www.sciops.esa.int/mars4>
- 21–23 **Solar System Formation and Observation Conference (SFO)**, Bern, Switzerland. <http://sfo.unibe.ch/>
- 27–29 **Workshop on Planetesimal Formation and Differentiation**, Washington, DC. <http://www.hou.usra.edu/meetings/planetesimal2013>
- 27–30 **2013 GSA Annual Meeting and Exposition**, Denver, Colorado. <http://www.geosociety.org/meetings/2013/>

November

- 4–8 **Second Kepler Science Conference**, Moffett Field, California. <http://kepler.arc.nasa.gov/Science/keplerconference>
- 11–14 **Second Exobiology Workshop**, Frejus, France. <http://www.exobiologie.fr/index.php/actualites/evenements/rencontres-sfe-2012/>
- 11–15 **First COSPAR Symposium: Planetary Systems of Our Sun and Other Stars, and the Future of Space Astronomy**, Bangkok, Thailand. www.cospar2013.gistda.or.th
- 27–30 **Astro-Engineering Workshop 2012**, Santiago, Chile. <http://www.aiuc.puc.cl/taller2012/>

December

- 9–13 **AGU Fall Meeting**, San Francisco, California. <http://fallmeeting.agu.org/2013/>

February 2014

- 5–7 **Vesta in the Light of Dawn**, Houston, Texas. <http://www.hou.usra.edu/meetings/vesta2014/>
- 9–14 **Exoclimates III: The Diversity of Planetary Atmospheres**, Davos, Switzerland. <http://www.exoclimates.org/>

March

- 17–21 **45th Lunar and Planetary Science Conference**, Location to be announced. <http://www.hou.usra.edu/meetings/lpsc2014>
- 17–21 **Search for Life Beyond the Solar System – Exoplanets, Biomarkers and Instruments**, Tucson, Arizona. <http://www.ebi2014.org>
- 17–21 **Search for Life Beyond the Solar System**, Tucson, Arizona. http://www.paignion.info/Tucson2014_placeholder_1.html