Liftoff

New Zealand's space exploration magazine

Issue 261
January-February 2011

Cometary snowstorm

- EPOXI reveals Hartley 2

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- **Apollo 14 – 40th anniversary**
- **Curiosity Mars rover update**

Liftoff

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NZSA News and Notices

Auckland meetings

The next Auckland meetings are on **7 March** and **4 April** at 7:45 pm at MOTAT, Great North Road, Western Springs (entry via Stadium Rd).

The Auckland Branch meets at MOTAT on the first Monday of each month (except January).

Wellington meetings

Good news for Wellington members! It is likely that meetings will resume at the Carter Observatory in the next few months (possibly April). Watch this space for details.

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Subscriptions 20010-2011 *(now reduced!)*

Subscription rates for 1 September 2010 to 31 August 2011 are as follows:

ORDINARY	$45
SENIOR CITIZEN	$40
STUDENT	$37.50

New subscriptions paid after 1 February 2011 may elect to receive *Liftoff* for only the second half year by paying half the above rates.

Note, too, that for each new member you introduce to the NZSA, providing they join for a full year and nominate you on their membership form, you will receive a credit of $5 against your next subscription. There is no limit to the number of credits you can qualify for.

Cover Photo: Comet Hartley 2 can be seen in glorious detail in this image from NASA's EPOXI mission. It was taken as the spacecraft flew by on 4 November 2010, from a distance of about 700 kilometres. The comet's nucleus, or main body, is approximately 2 kilometres long and .4 kilometres at the "neck," or most narrow portion. Jets can be seen streaming out of the nucleus. The mission's Medium-Resolution Instrument was used to capture this view. The sun is to the right. (NASA/JPL-Caltech/UMD)

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Editor's Corner

2011 is a significant year for space exploration in more ways than one. On 12 April it will be 50 years to the days since the first human space flight, by the Soviet Union's Yuri Gagarin. Back then the US and the Soviets were in the early stages of the so-called "space race" that would culminate, in July 1969, with the first lunar landing by Apollo 11.

How ironic, then, that in this 50th anniversary year, US human spaceflight capability will cease for the foreseeable future with the retirement of the Space Shuttle fleet. It may be as little as three years before a new US-built crewed spacecraft flies, but more likely it will be five years, or more. In the meantime the US has to rely on paying its old rivals – now firm partners – the Russians to fly US astronauts to the International Space Station, at $US50 million or more per crewmember.

This sorry state of affairs represents a failure of the imagination and of policy-making on the part of the US Government – the administrative *and* executive branches, and the various agencies involved including NASA. And it's not as if this is the first time such a gap has happened: six years elapsed between the final Apollo flight (ASTP) in 1975 and the first Shuttle launch in 1981. The difference then was that there was no International Space Station to supply and crew.

Work on a Shuttle replacement should have commenced long before it did, and a good argument could be made that it would be smart for the US to retain the Shuttle capability, even if at a reduced flight rate of only a couple of mission per year, until such a replacement is ready. But it's the old story: no bucks, no Buck Rogers, and the Obama administration has shown that it is no great supporter of US human spaceflight by putting all its bets on spacecraft that haven't even left the drawing board yet.

On the upside, it's going to be a record year for solar system exploration, as outlined in the last issue of *Liftoff*. Highlights include the launch of the Curiosity Mars rover (see page 20) and the Juno Jupiter mission, as well as asteroid and comet flybys. Plenty to be excited about, then!

-- *David Maclennan*

Dragon flies

Launch of the Dragon test spacecraft (NASA)

On 8 December 2010 SpaceX became the first commercial company in history to re-enter from low-Earth orbit. SpaceX launched its Dragon spacecraft into low-Earth orbit atop a Falcon 9 rocket at 10:43 a.m. EST from Launch Complex 40 at the Air Force Station at Cape Canaveral. The Dragon spacecraft orbited the Earth at speeds greater than 27,353 kilometres per hour, reentered the Earth's atmosphere and landed in the Pacific Ocean shortly after 2:00 p.m. EST.

This marks the first time a commercial company has successfully recovered a spacecraft reentering from low-Earth orbit. It is a feat performed by only six nations or government agencies: the United States, Russia, China, Japan, India, and the European Space Agency. It is also the first flight under NASA's COTS program to develop commercial supply services to the International Space Station. After the Space Shuttle retires, SpaceX will fly at least 12 missions to carry cargo to and from the ISS as part of the Commercial Resupply Services contract for NASA. The Falcon 9 rocket and Dragon spacecraft were designed to one day carry astronauts; both the COTS and CRS missions will yield valuable flight experience toward this goal.

SpaceX is developing a family of launch vehicles and spacecraft that will increase reliability and performance of space transportation, while ultimately reducing costs by a factor to ten. With the Falcon 1 and Falcon 9 rockets, SpaceX has a diverse manifest of launches to deliver commercial satellites to orbit. After the Space shuttle retires, the Falcon 9 and SpaceX's Dragon spacecraft will start carrying cargo, including live plants and animals, to and from the ISS for NASA. Falcon 9 and Dragon were developed to one day carry astronauts. – *Ed Case, NZSA*

Hayabusa returns asteroid samples

After all the drama, the Japanese Aerospace Exploration Agency's Hayabusa spacecraft *did* bring home to Earth tiny pieces of asteroid Itokawa.

"It's an incredible feeling to have another world right in the palm of your hand," says Mike Zolensky, Associate Curator for Interplanetary Dust at the Johnson Space Center, and one of the three non-Japanese members of the science team. "We're seeing for the first time, up close, what an asteroid is actually made of!" He has good reason to be excited. Asteroids formed at the dawn of our solar system, so studying these samples can teach us how it formed and evolved.

Hayabusa launched in 2003 and set out on a billion kilometre voyage to Itokawa, arriving a little over two years later. In 2005, the spacecraft performed a spectacular feat -- landing on the asteroid's surface. The hope was to capture samples from the alien world. But there was a problem. The projectiles set to blast up dust from the surface failed to fire, leaving only the particles kicked up from landing for collection. Did any asteroid dust made it into the collection chamber?

Zolensky and other eager scientists, with eyes riveted skyward, watched the answer plunge back into Earth's atmosphere at 43,443 kilometres per hour on the night of 13 June 2010. Hayabusa's main bus shattered over the Australian outback during reentry, and the intact sample return capsule drifted to Earth via parachute. "We were mesmerized," says Zolensky. "As we waited for it to land, no one even moved."

But the waiting was only just beginning. Because attempting retrieval of the capsule in the dark was too dangerous, he spent a sleepless night before getting a closer look.

"I was one of the first people to board the helicopter that flew to the landing site the next morning. And I was the first person to walk up to the capsule."

He had to stop within 10 feet of it. More waiting. "I watched the retrieval team recover it. They wore face masks and gloves and blue padded suits. They had to disable the unexploded parachute release charges, and that was pretty nerve wracking. Then they picked up the capsule oh so carefully and placed it in a box."

The precious cargo was flown via charter jet to Japan for analysis. Guess who was waiting for it when it arrived? "I was ready to work," says Zolensky, who along with fellow team member Scott Sandford of NASA Ames Research Center had traveled to Japan for the opening. "The first results were disheartening. When we scanned the capsule with a modified CAT scan, there appeared to be nothing inside."

Next, Japanese members of the team painstakingly dismantled the capsule, piece by piece. "They had to use a micromanipulator to avoid contamination, and the process took months." More waiting.

"Once we got inside the capsule, we could see dust on the interior walls. I thought to myself, 'we've got asteroid dust here!' But there was still a possibility the contents could be contamination from launch or reentry and landing." The next step was to remove and analyze the particles -- another agonizingly slow process, and more waiting. "The particles are each smaller than the diameter of a human hair. We finally used a Teflon spatula to sweep out a large number of tiny particles."

Though most of the particles are still in the capsule, the team has removed and analyzed 2000 of them with an electron microscope. And? "At least 1500 of them are from the asteroid! We're seeing pieces of another world. It looks like a very primitive type asteroid. We'll tell you more in March at the 2011 Lunar and Planetary Science Conference in Houston."

This is only the third time ever that samples of a solid extraterrestrial body have been brought back to Earth. The Apollo astronauts and Soviet Luna robots were first – they brought us samples of moondust. And NASA's Stardust spacecraft returned samples of comet Wild 2 in 2006.

"The Japanese people are thrilled, and so are we. The emperor even requested a personal tour of the capsule. This is their Apollo mission. They're showing us all a new world!" - *Science@NASA (with edits)*

Hubble finds most distant galaxy candidate ever seen in universe

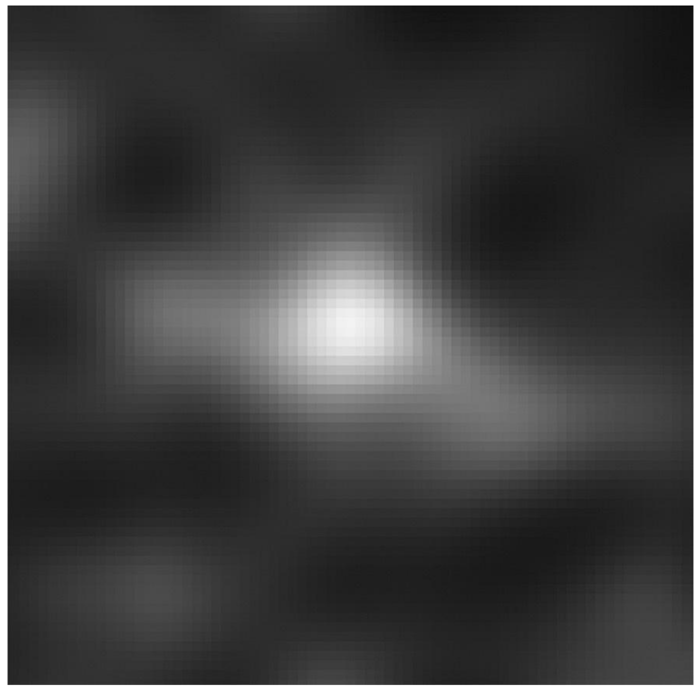
Astronomers have pushed NASA's Hubble Space Telescope to its limits by finding what is likely to be the most distant object ever seen in the universe. The object's light traveled 13.2 billion years to reach Hubble, roughly 150 million years longer than the previous record holder. The age of the universe is approximately 13.7 billion years.

The tiny, dim object is a compact galaxy of blue stars that existed 480 million years after the big bang. More than 100 such mini-galaxies would be needed to make up our Milky Way. The new research offers surprising evidence that the rate of star birth in the early universe grew dramatically, increasing by about a factor of 10 from 480 million years to 650 million years after the big bang.

Astronomers don't know exactly when the first stars appeared in the universe, but every step farther from Earth takes them deeper into the early formative years when stars and galaxies began to emerge in the aftermath of the big bang.

"These observations provide us with our best insights yet into the earlier primeval objects that have yet to be found," said Rychard Bouwens of the University of Leiden in the Netherlands. Bouwens and Illingworth report the discovery in the 27 January issue of the British science journal *Nature*.

This observation was made with the Wide Field Camera 3 starting just a few months after it was installed in the observatory in May 2009, during the last NASA space shuttle servicing mission to Hubble. After more than a year of detailed observations and analysis, the object was positively identified in the camera's Hubble Ultra Deep Field-Infrared data taken in the late summers of 2009 and 2010.



Long, long ago in a galaxy far, far away… (NASA)

The object appears as a faint dot of starlight in the Hubble exposures. It is too young and too small to have the familiar spiral shape that is characteristic of galaxies in the local universe. Although its individual stars can't be resolved by Hubble, the evidence suggests this is a compact galaxy of hot stars formed more than 100 to 200 million years earlier from gas trapped in a pocket of dark matter. "We're peering into an era where big changes are afoot," said Garth Illingworth of the University of California at Santa Cruz. "The rapid rate at which the star birth is changing tells us if we go a little further back in time we're going to see even more dramatic changes, closer to when the first galaxies were just starting to form."

The proto-galaxy is only visible at the farthest infrared wavelengths observable by Hubble. Observations of earlier times, when the first stars and galaxies were forming, will require Hubble's successor, the James Webb Space Telescope (JWST).

The hypothesized hierarchical growth of galaxies -- from stellar clumps to majestic spirals and ellipticals -- didn't become evident until the Hubble deep field exposures. The first 500 million years of the universe's existence, from a z of 1000 to 10, is the missing chapter in the hierarchical growth of galaxies. It's not clear how the universe assembled structure out of a darkening, cooling fireball of the big bang. As with a developing embryo, astronomers know there must have been an early period of rapid changes that would set the initial conditions to make the universe of galaxies what it is today.

Fermi catches thunderstorms hurling antimatter into space

Scientists using NASA's Fermi Gamma-ray Space Telescope have detected beams of antimatter produced above thunderstorms on Earth, a phenomenon never seen before. Scientists think the antimatter particles were formed in a terrestrial gamma-ray flash (TGF), a brief burst produced inside thunderstorms and shown to be associated with lightning. It is estimated that about 500 TGFs occur daily worldwide, but most go undetected.

"These signals are the first direct evidence that thunderstorms make antimatter particle beams," said Michael Briggs, a member of Fermi's Gamma-ray Burst Monitor (GBM) team at the University of Alabama in Huntsville (UAH).

Fermi is designed to monitor gamma rays, the highest energy form of light. When antimatter striking Fermi collides with a particle of normal matter, both particles immediately are annihilated and transformed into gamma rays. The GBM has detected gamma rays with energies of 511,000 electron volts, a signal indicating an electron has met its antimatter counterpart, a positron.

The Fermi Gamma Ray Space Telescope (NASA)

Although Fermi's GBM is designed to observe high-energy events in the universe, it's also providing valuable insights into this strange phenomenon. The GBM constantly monitors the entire celestial sky above and the Earth below. The GBM team has identified 130 TGFs since Fermi's launch in 2008.

The spacecraft was located immediately above a thunderstorm for most of the observed TGFs, but in four cases, storms were far from Fermi. In addition, lightning-generated radio signals detected by a global monitoring network indicated the only lightning at the time was hundreds or more kilometres away. During one TGF, which occurred on 4 December 2009, Fermi was located over Egypt. But the active storm was in Zambia, some 4,505 kilometres to the south. The distant storm was below Fermi's horizon, so any gamma rays it produced could not have been detected.

"Even though Fermi couldn't see the storm, the spacecraft nevertheless was magnetically connected to it," said Joseph Dwyer at the Florida Institute of Technology in Melbourne, Fla. "The TGF produced high-speed electrons and positrons, which then rode up Earth's magnetic field to strike the spacecraft." The beam continued past Fermi, reached a location, known as a mirror point, where its motion was reversed, and then hit the spacecraft a second time just 23 milliseconds later. Each time, positrons in the beam collided with electrons in the spacecraft. The particles annihilated each other, emitting gamma rays detected by Fermi's GBM.

Scientists long have suspected TGFs arise from the strong electric fields near the tops of thunderstorms. Under the right conditions, they say, the field becomes strong enough that it drives an upward avalanche of electrons. Reaching speeds nearly as fast as light, the high-energy electrons give off gamma rays when they're deflected by air molecules. Normally, these gamma rays are detected as a TGF. But the cascading electrons produce so many gamma rays that they blast electrons and positrons clear out of the atmosphere. This happens when the gamma-ray energy transforms into a pair of particles: an electron and a positron. It's these particles that reach Fermi's orbit.

The detection of positrons shows many high-energy particles are being ejected from the atmosphere. In fact, scientists now think that all TGFs emit electron/positron beams. "The Fermi results put us a step closer to understanding how TGFs work," said Steven Cummer at Duke University. "We still have to figure out what is special about these storms and the precise role lightning plays in the process."

LRO creating unprecedented topographic map of Moon

NASA's Lunar Reconnaissance Orbiter is allowing researchers to create the most precise and complete map to date of the moon's complex, heavily cratered landscape. "This dataset is being used to make digital elevation and terrain maps that will be a fundamental reference for future scientific and human exploration missions to the moon," said Dr. Gregory Neumann of NASA's Goddard Space Flight Center in Greenbelt, Md. "After about one year taking data, we already have nearly 3 billion data points from the Lunar Orbiter Laser Altimeter on board the LRO spacecraft, with near-uniform longitudinal coverage. We expect to continue to make measurements at this rate through the next two years of the science phase of the mission and beyond. Near the poles, we expect to provide near-GPS-like navigational capability as coverage is denser due to the spacecraft's polar orbit."

The Lunar Orbiter Laser Altimeter (LOLA) works by propagating a single laser pulse through a Diffractive Optical Element that splits it into five beams. These beams then strike and are backscattered from the lunar surface. From the return pulse, the LOLA electronics determines the time of flight which, accounting for the speed of light, provides a precise measurement of the range from the spacecraft to the lunar surface. Range measurements, combined with accurate tracking of the spacecraft's location, are used to build a map revealing the contours of the lunar landscape. The five beams create a two-dimensional spot pattern that unambiguously reveals slopes. LOLA will also measure the spreading of the return pulse to get the surface roughness and the change in the transmitted compared to the return energy of the pulse to determine surface reflectance.

The new LOLA maps are more accurate and sample more places on the lunar surface than any available before. "The positional errors of image mosaics of the lunar far side, where direct spacecraft tracking – the most accurate -- is unavailable, have been one to ten kilometres," said Neumann. "We're beating these down to the level of 30 metres or less spatially and one metre vertically. At the poles, where illumination rarely provides more than a glimpse of the topography below the crater peaks, we found systematic horizontal errors of hundreds of metres as well." In terms of coverage, the nearly three billion range measurements so far by LRO compare to about eight million to nine million each from three recent international lunar missions, according to Neumann. "They were limited to a mile or so between individual data points, whereas our measurements are spaced about 57 metres apart in five adjacent tracks separated by about 15 metres."

"Recent papers have clarified some aspects of lunar processes based solely on the more precise topography provided by the new LOLA maps," adds Neumann, "such as lunar crater density and resurfacing by impacts, or the formation of multi-ring basins."

"The LOLA data also allow us to define the current and historical illumination environment on the moon," said Neumann. Lunar illumination history is important for discovering areas that have been shaded for long periods. Such places, typically in deep craters near the lunar poles, act like cold storage, and are capable of accumulating and preserving volatile material like water ice.

The landscape in polar craters is mysterious because their depths are often in shadow. The new LOLA dataset is illuminating details of their topography for the first time. "Until LRO and the recent Japanese Kaguya mission, we had no idea of what the extremes of polar crater slopes were," said Neumann. "Now, we find slopes of 36 degrees over several kilometers (several thousands of yards) in Shackleton crater, for example, which would make traverses quite difficult and apparently causes landslides. The LOLA measurements of shadowed polar crater slopes and their surface roughness take place at scales from lander size to kilometers. These measurements are helping the LRO science team model the thermal environment of these craters, and team members are developing temperature maps of them."

NASA research team reveals Moon has Earth-like core

State-of-the-art seismological techniques applied to Apollo-era data suggest our Moon has a core similar to Earth's. Uncovering details about the lunar core is critical for developing accurate models of the Moon's formation. The data sheds light on the evolution of a lunar dynamo -- a natural process by which our Moon may have generated and maintained its own strong magnetic field.

The team's findings suggest the Moon possesses a solid, iron-rich inner core with a radius of nearly 241.3 kilometres and a fluid, primarily liquid-iron outer core with a radius of roughly 329 kilometres. Where it differs from Earth is a partially molten boundary layer around the core estimated to have a radius of nearly 482.7 kilometres. The research indicates the core contains a small percentage of light elements such as sulphur, echoing new seismology research on Earth that suggests the presence of light elements -- such as sulphur and oxygen -- in a layer around our own core.

The researchers used extensive data gathered during the Apollo-era Moon missions. The Apollo Passive Seismic Experiment consisted of four seismometers deployed between 1969 and 1972, which recorded continuous lunar seismic activity until late 1977. "We applied tried and true methodologies from terrestrial seismology to this legacy data set to present the first-ever direct detection of the Moon's core," said Renee Weber, lead researcher and space scientist at NASA's Marshall Space Flight Center in Huntsville, Ala.

An Apollo Passive Seismic Experiment deployed on the lunar surface (NASA)

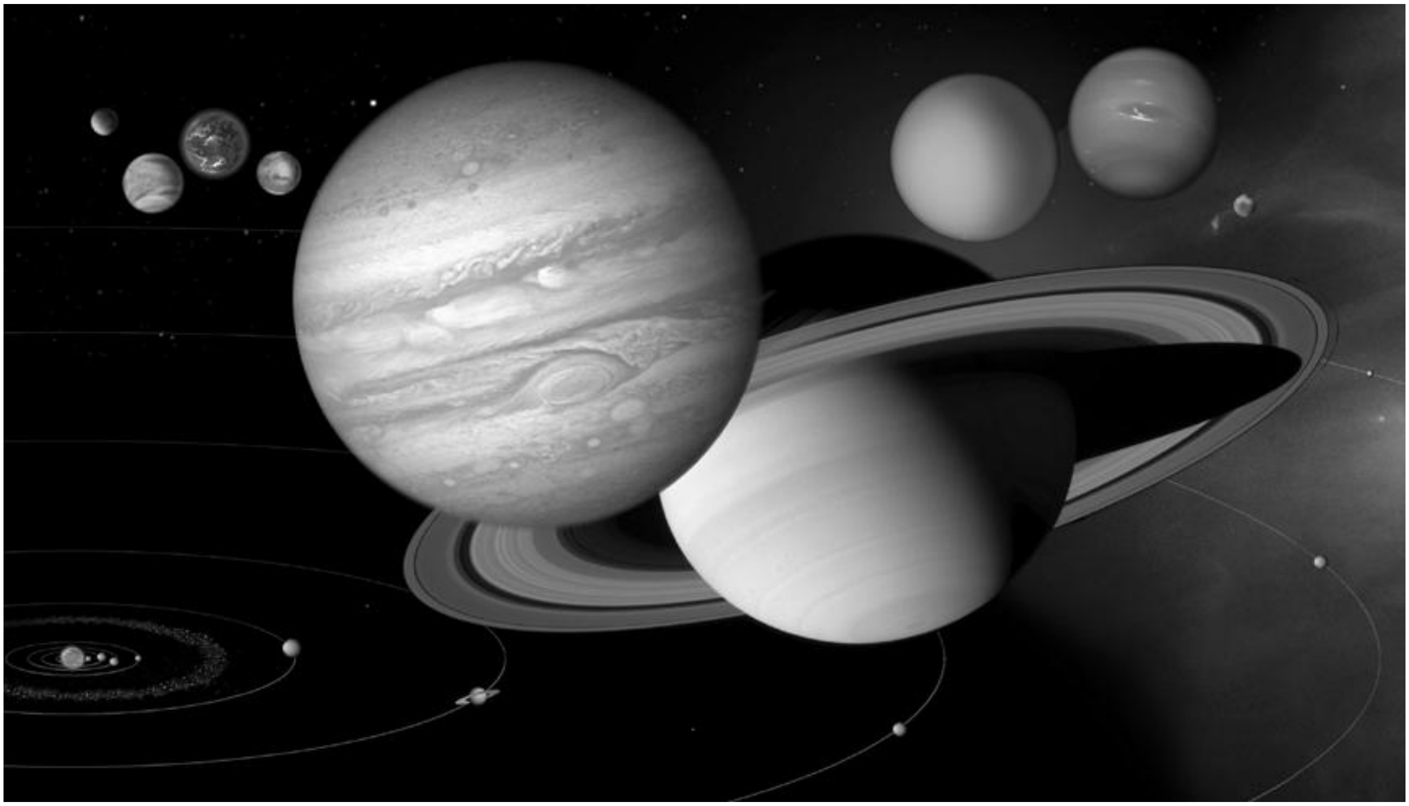
The team also analyzed Apollo lunar seismograms using array processing, techniques that identify and distinguish signal sources of Moonquakes and other seismic activity. The researchers identified how and where seismic waves passed through or were reflected by elements of the Moon's interior, signifying the composition and state of layer interfaces at varying depths.

Although sophisticated satellite imaging missions to the Moon made significant contributions to the study of its history and topography, the deep interior of Earth's sole natural satellite remained a subject of speculation and conjecture since the Apollo era. Researchers previously had inferred the existence of a core, based on indirect estimates of the Moon's interior properties, but many disagreed about its radius, state and composition.

A primary limitation to past lunar seismic studies was the wash of "noise" caused by overlapping signals bouncing repeatedly off structures in the Moon's fractionated crust. To mitigate this challenge, Weber and the team employed an approach called eismogram stacking, or the digital partitioning of signals. Stacking improved the signal-to-noise ratio and enabled the researchers to more clearly track the path and behavior of each unique signal as it passed through the lunar interior.

"We hope to continue working with the Apollo seismic data to further refine our estimates of core properties and characterize lunar signals as clearly as possible to aid in the interpretation of data returned from future missions," Weber said.

Future NASA missions will help gather more detailed data. The Gravity Recovery and Interior Laboratory, or GRAIL, is a NASA Discovery-class mission set to launch this year. The



The planets may have gained the final portions of their mass from asteroid or comet impacts more than 4.5 billion years ago (NASA)

mission consists of twin spacecraft that will enter tandem orbits around the Moon for several months to measure the gravity field in unprecedented detail. The
mission also will answer longstanding questions about Earth's Moon and provide scientists a better understanding of the satellite from crust to core, revealing subsurface structures and, indirectly, its thermal history.

NASA and other space agencies have been studying concepts to establish an International Lunar Network -- a robotic set of geophysical monitoring stations on the Moon -- as part of efforts to coordinate international missions during the coming decade.

NASA scientists theorize final growth spurt for planets

A team of NASA-funded researchers has unveiled a new theory that contends planets gained the final portions of their mass from a limited number of large comet or asteroid impacts more than 4.5 billion years ago. These impacts added less than 1% of the planets' mass. Scientists hope the research not only will provide a better historical
picture of the birth and evolution of Earth, the Moon and Mars, but also allow researchers to better explore what happened in our solar system's beginning and middle stages of planet formation.

"No one has a model of precisely what happened at the end of planet formation-we've had a broad idea-but variables such as impactor size, the approximate timing of the impacts, and how they affect the evolution of the planets are unknown," said William Bottke, principal investigator from the Southwest Research Institute (SWRI) in Boulder, Colo. "This research hopefully provides better insights into the early stages of planet formation."

The team used numerical models, lunar samples returned by Apollo astronauts and meteorites believed to be from Mars to develop its findings. The scientists examined the abundances of elements such as gold and platinum in the mantles, or layers beneath the crust, of Earth, the Moon and Mars. Consistent with previous studies, they concluded the elements were added by a process called late accretion during a planet's final growth spurt. "These impactors probably represent the largest objects to hit Earth
since the giant impact that formed our Moon," Bottke said. "They also may be responsible for the accessible abundance of gold, platinum, palladium, and other important metals used by our society today in items ranging from jewelry to our cars' catalytic convertors."

The results indicate the largest Earth impactor was between 2,413 - 3,218 kilometres in diameter, roughly the size of Pluto. Because it is smaller than Earth, the moon avoided such enormous projectiles and was only hit by impactors 241 – 321 kilometres wide. These impacts may have played important roles in the evolution of both worlds. For example, the projectiles that struck Earth may have modified the orientation of its spin axis by 10 degrees, while those that hit the Moon may have delivered water to its mantle.

"Keep in mind that while the idea the Earth-Moon system owes its existence to a single, random event was initially viewed as radical, it is now believed that large impacts were commonplace during the final stages of planet formation,' Bottke said. "Our new results provide additional evidence that the effects of large impacts did not end with the Moon-forming event."

Kepler mission discovers its first rocky planet

NASA's Kepler mission confirmed the discovery of its first rocky planet, named Kepler-10b. Measuring 1.4 times the size of Earth, it is the smallest planet ever discovered outside our solar system. The discovery of this planet, called an exoplanet, is based on more than eight months of data collected by the spacecraft from May 2009 to early January 2010.

"All of Kepler's best capabilities have converged to yield the first solid evidence of a rocky planet orbiting a star other than our sun," said Natalie Batalha, Kepler's deputy science team lead at NASA's Ames Research Center in Moffett Field, Calif., and primary author of a paper on the discovery accepted by the Astrophysical Journal. "The Kepler team made a commitment in 2010 about finding the telltale signatures of small planets in the data, and it's beginning to pay off."

Kepler's ultra-precise photometer measures the tiny decrease in a star's brightness that occurs when a planet crosses in front of it. The size of the planet can be derived from these periodic dips in brightness. The distance between the planet and the star is calculated by measuring the time between successive dips as the planet orbits the star.

Kepler is the first NASA mission capable of finding Earth-size planets in or near the habitable zone, the region in a planetary system where liquid water can exist on the planet's surface. However, since it orbits once every 0.84 days, Kepler-10b is more than 20 times closer to its star than Mercury is to our sun and not in the habitable zone.

Kepler-10 was the first star identified that could potentially harbor a small transiting planet, placing it at the top of the list for ground-based observations with the W.M. Keck Observatory 10-meter telescope in Hawaii. Scientists waiting for a signal to confirm Kepler-10b as a planet were not disappointed. Keck was able to measure tiny changes in the star's spectrum, called Doppler shifts, caused by the telltale tug exerted by the orbiting planet on the star.

"The discovery of Kepler 10-b is a significant milestone in the search for planets similar to our own," said Douglas Hudgins, Kepler program scientist at NASA Headquarters in Washington. "Although this planet is not in the habitable zone, the exciting find showcases the kinds of discoveries made possible by the mission and the promise of many more to come."

Knowledge of the planet is only as good as the knowledge of the star it orbits. Because Kepler-10 is one of the brighter stars being targeted by Kepler, scientists were able to detect high-frequency variations in the star's brightness generated by stellar oscillations, or starquakes. This analysis allowed scientists to pin down Kepler-10b's properties.

There is a clear signal in the data arising from light waves that travel within the interior of the star. Kepler Asteroseismic Science Consortium scientists use the information to better understand the star, just as earthquakes are used to learn about Earth's interior structure. As a result of this analysis, Kepler-10 is one of the most well-characterized planet-hosting stars in the universe. That's good news for the team studying Kepler-10b. Accurate stellar properties yield accurate planet properties. In the case of Kepler-10b, the picture that emerges is of a rocky planet with a mass 4.6 times that of Earth and with an average density of 8.8 grams per cubic centimeter -- similar to that of an iron dumbbell.

Planck mission peels back layers of the universe

The Planck mission has released a new data catalogue from initial maps of the entire sky. The catalogue includes thousands of never-before-seen dusty cocoons where stars are forming, and some of the most massive clusters of galaxies ever observed. Planck is a European Space Agency mission with significant contributions from NASA.

Planck launched in May 2009 on a mission to detect light from just a few hundred thousand years after the Big Bang, an explosive event at the dawn of the universe approximately 13.7 billion years ago. The spacecraft's state-of-the-art detectors ultimately will survey the whole sky at least four times, measuring the cosmic microwave background, or radiation left over from the Big Bang. The data will help scientists decipher clues about the evolution, fate and fabric of our universe. While these cosmology results won't be ready for another two years or so, early observations of specific objects in our Milky Way galaxy, as well as more distant galaxies, are being released.

"The data we're releasing now are from what lies between us and the cosmic microwave background," said Charles Lawrence, the U.S. project scientist for Planck at NASA's Jet Propulsion Laboratory in Pasadena, Calif. We ultimately will subtract these data out to get at our cosmic microwave background signal. But by themselves, these early observations offer up new information about objects in our universe -- both close and far away, and everything in between."

Planck observes the sky at nine wavelengths of light, ranging from infrared to radio waves. Its technology has greatly improved sensitivity and resolution over its predecessor missions, NASA's Cosmic Background Explorer and Wilkinson Microwave Anisotropy Probe. The result is a windfall of data on known and never-before-seen cosmic objects. Planck has catalogued approximately 10,000 star-forming "cold cores," thousands of which are newly discovered. The cores are dark and dusty nurseries where baby stars are just beginning to take shape. They also are some of the coldest places in the universe. Planck's new catalogue includes some of the coldest cores ever seen, with temperatures as low as seven degrees above absolute zero. In order to see the coldest gas and dust in the Milky Way, Planck's detectors were chilled to only 0.1 Kelvin.

The new catalogue also contains some of the most massive clusters of galaxies known, including a handful of newfound ones. The most massive of these holds the equivalent of a million billion suns worth of mass, making it one of the most massive galaxy clusters known. Galaxies in our universe are bound together into these larger clusters, forming a lumpy network across the cosmos. Scientists study the clusters to learn more about the evolution of galaxies and dark matter and dark energy -- the exotic substances that constitute the majority of our universe.

"Because Planck is observing the whole sky, it is giving us a comprehensive look at how all the smaller structures of the universe are connected to the whole," said Jim Bartlett, a U.S. Planck team member at JPL and the Astroparticule et Cosmologie-Universite Paris Diderot in France.

Planck's new catalogue also includes unique data on the pools of hot gas that permeate roughly 14,000 smaller clusters of galaxies; the best data yet on the cosmic infrared background, which is made up of light from stars evolving in the early universe; and new observations of extremely energetic galaxies spewing radio jets. The catalogue covers about one-and-a-half sky scans.

Apollo 14: Flight to Fra Mauro

By David Maclennan

The Apollo 14 LM Antares rests at a slight angle in the Moon's Fra Mauro highlands. Cone Crater ridge can be seen sloping at left (NASA/David Harland)

Apollo 14 is my favourite of all the Apollo flights, for a whole bunch of reasons. For one, it was the first Apollo flight since I'd begun corresponding with the various NASA public affairs offices a few months earlier. Thus I had a fair amount of pre-flight information on this mission, including a nice colour lithograph of the crew which had pride of place on my bedroom wall (already covered with Apollo stuff as it was!) It was also something of a golden summer here: I'd done School Cert in November and a couple of weeks before launch I received my results: passed with flying colours (not that there'd been any doubt!) So I was having a relaxing holiday and looking forward to my 6th form year. Then there was this girl I seriously fancied… ah, but that's a whole other story!

Starry-eyed space cadet that I was in those days, I'd written to the Apollo 14 crew to wish them luck, and a couple of weeks prior to launch what should turn up in the mailbox but a letter of thanks from Alan Shepard himself! I was pretty chuffed at that. He was something of a hero of mine back then, another reason why Apollo 14 is my favourite Apollo.

The US Information Service in Wellington got a stack of little pamphlets outlining the flight's objectives. I had a swag of these, and some Apollo programme logo button badges, and I was handing them out to everyone I met. I also organized a display on the mission in the Taita College library (the mission happened during the first week of the new school year).

So Apollo 14 really marked the start of an unofficial career as a space publicist – and 40 years later, I'm still at it! – David Maclennan

Apollo 14 is one of those missions that often gets overlooked or only briefly mentioned in space documentaries. Yet as the return-to-flight mission following the near-disaster of Apollo 13, it was one of the most crucial flights of the whole Apollo programme, and while less eventful that the previous flight, it too had its share of heart-stopping moments, beginning almost as soon as it left Earth orbit.

Apollo 14 was originally to have flown in mid-1970 to a landing site near Littrow crater, near the eastern "shore" of the Moon's Mare Serenitatis region. A site of volcanic origin, Littrow was of interest to scientists because it appeared to be a layer of pyroclastic ash. However, in the reviews that followed Apollo 13 it was decided that the Fra Mauro highlands (the intended landing site for that mission) was more geologically important, and in May 1970 the site was reassigned to Apollo 14, now scheduled for early 1971.

As well as a return to flight for the Apollo spacecraft, Apollo 14 also marked a return to flight for its commander, Alan B Shepard, Jr., who a decade earlier, on 5 May 1961, became America's first man in space when he flew a sub-orbital 15-minute flight aboard a Mercury capsule named *Freedom 7*. (Apollo 14's Saturn 5 launcher dwarfed the puny Redstone that launched Shepard in 1961 – in fact, just the escape rocket atop the Saturn had nearly twice the thrust of a Redstone.)

Shepard was due to make a Gemini flight but was grounded from all flying (other than as a passenger) after developing an ear disorder, Meniere's syndrome. In 1969 he underwent a new surgical procedure to correct this, and was subsequently returned to flight status. He asked for the Apollo 13 command, but the NASA brass felt he needed more training on Apollo so he wound up with Apollo 14 (lucky for him!)

Shepard's crewmates aboard Apollo 14 were rookies Edgar D Mitchell (Lunar Module Pilot) and Stuart A Roosa (Command Module Pilot). Both men were part of the 1966 astronaut class, and Mitchell in particular was an expert when it came to the Lunar Module and its systems. In one sense, this crew was the least experienced of all the Apollo crews in terms of flight time, but the delay in the mission meant that they were one of the best trained by the time Apollo 14 finally flew.

Following Apollo 13 a number of changes were incorporated into the spacecraft to increase chances of survival should a similar mishap occur. A third oxygen tank was added and the internal construction of the tanks themselves was modified. An auxiliary battery was also installed.

Early dramas

Apollo 14 launched on the afternoon of 31 January 1971 from the Kennedy Space Center, Florida. Launch was delayed 40 minutes due to passing shower clouds – the first time an Apollo launch had slipped, but after Apollo 12's lightning strike the NASA launch team was taking no chances. To make up for the 40-minute delay, Apollo 14's translunar coast trajectory was tweaked to ensure they were on the original timeline by the time they reached the Moon.

The first of Apollo 14's dramas came a few hours after launch, when Stu Roosa performed the all-important transposition, docking and extraction manoevre to remove the Lunar Module from its berth atop of the Saturn S-IVB stage. When Roosa moved the Command/Service Module *Kittyhawk* in to dock with the LM *Antares*, nothing happened – the latches did not engage! It was only on the sixth attempt, nearly two hours later, that Roosa succeeded in docking with the LM. The crew examined the docking probe once the two craft were firmly connected but could find no obvious fault. At the back of everyone's mind was the fact that the system would have to work again after Shepard and Mitchell had left the lunar surface to rejoin Roosa in orbit. If it failed then, a tricky spacewalk would be required to get the two men back inside *Kittyhawk*.

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Here in New Zealand it was Monday 1 February – the last day of the school holidays, and a warm sunny day. Given that the launch occurred at 9:03 am NZT, I had naively hoped that the 9 a.m. radio news bulletin would have switched to a live Voice of America feed of the launch. I was rather incensed that they did not – after all, this was history in the making! However, another friend, Brian, rang just before launch, and he was tuned to Radio Australia. Thanks to him holding the receiver near the radio, I got to hear the launch in the end. Three hours later I had a couple of friends at our house having one of our occasional day-long sessions listening to records, when the phone rang. It was Brian again, phoning with the news that they couldn't dock with the LM. "They can't dock!" I called out to my friends, who stopped in their tracks. A couple of hours later we were very relieved to hear that Roosa had finally succeeded. – DM

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Radar problems threaten landing

The rest of the trip to the Moon was uneventful, and on 5 February the crew were safely in lunar orbit. At about the same time, the spent SIV-B third stage crashed into the Moon as planned, with the signal being picked up by the seismometer left by Apollo 12. Shepard and Mitchell then prepared to undock *Antares* from *Kittyhawk* and head down to the surface.

Almost as soon as the two craft separated, Shepard and Mitchell discovered a potentially serious problem: one of the craft's two guidance systems, the Abort Guidance System (AGS) had somehow triggered. Had they been trying to land, this would have automatically jettisoned *Antares*' descent stage and initiated a rendezvous with *Kittyhawk*. Engineers at Houston decided there must have been a short circuit in the system, and while *Antares* was behind the Moon a software patch was hurriedly written by engineers at the Massachusetts Institute of Technology (where the Apollo guidance computer was developed) to fix the problem. Once transmitted to the crew, Mitchell raced against the clock to key in the patch, which rendered the AGS passive.

All looked good, so the crew were given a "go" for powered descent to the Moon. However, another serious problem now

Apollo 14 launch, 31 January 1971 (NASA)

reared its head: Antares' landing radar, designed to provide altitude readings to the LM's primary guidance system, failed to lock on. Without altitude and descent rate information, mission rules dictated an abort. To everyone's relief, the crew were able to re-initialise the system by cycling the relevant circuit breaker on and off, but it took several minute to do this. Meanwhile, Shepard and Mitchell continued to fly a normal decent profile.

(What would have happened if the radar had not locked on? Would Shepard have ignored mission rules and used his skill as a pilot to eyeball a landing? When asked this question years later in an interview, Shepard merely smiled slyly and said, "You'll never know!")

Shepard set Antares down a mere 50 metres from the target point. "We made a good landing," he announced matter-of-factly.

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Shepard and Mitchell weren't the only ones having electrical problems on landing day. The radio at home chose this day, of all days, to conk out! This meant I had to listen to the landing – which, unlike the launch, the National Programme did choose to broadcast – on Mum's little transistor radio. Landing itself was at 9:18 p.m. NZT that evening. – DM

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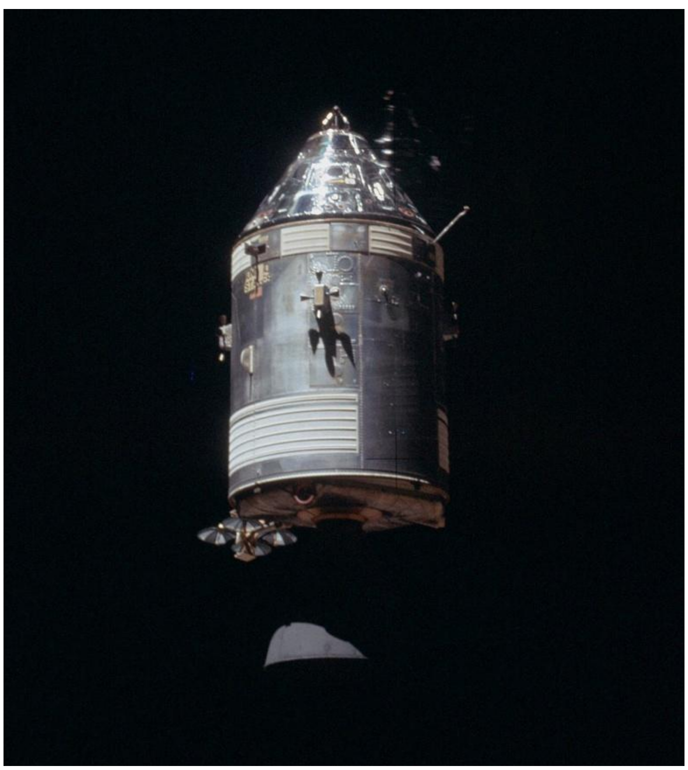
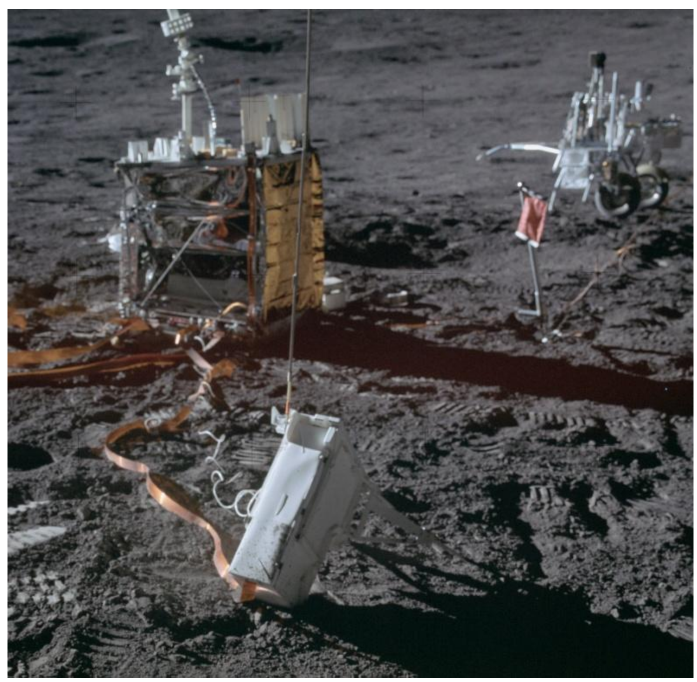
APOLLO 14
Shepard





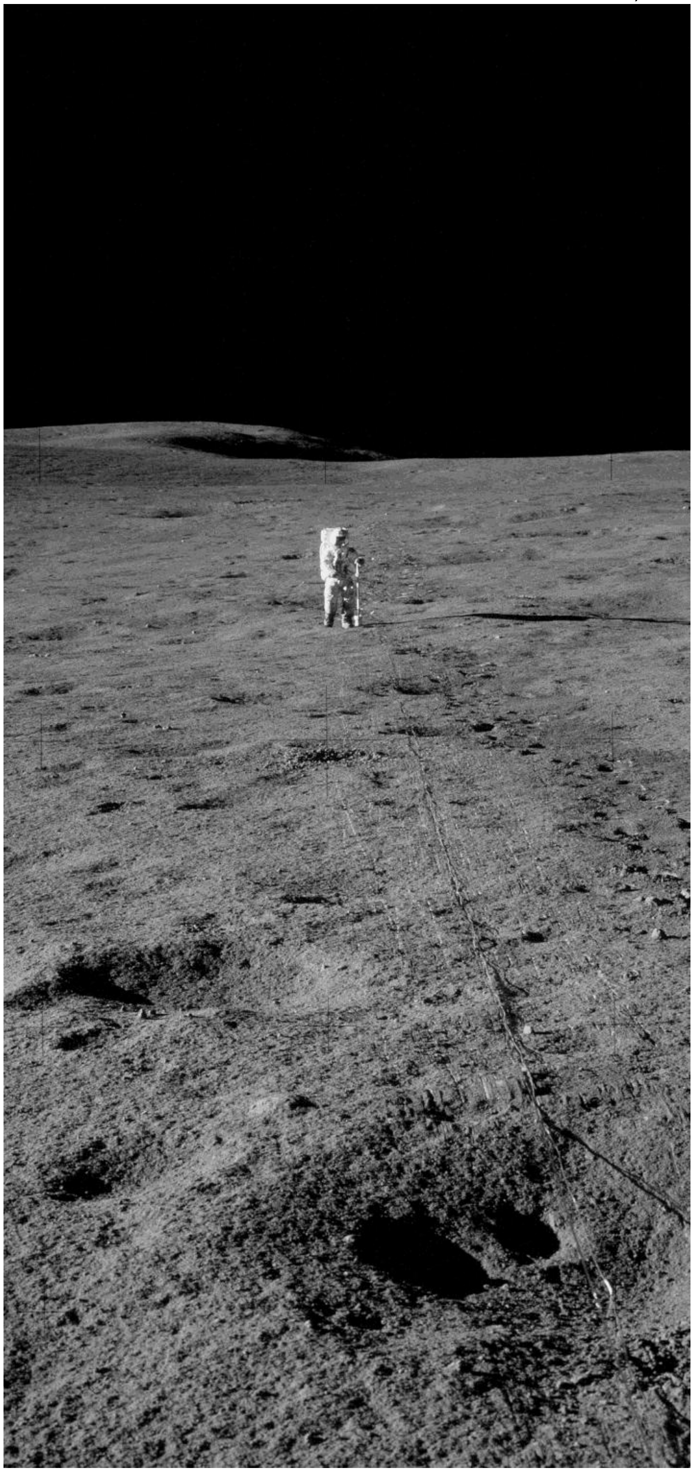
Previous page top: Apollo 14 crew (L-R) Roosa, Shepard, Mitchell

Previous page bottom: Shepard steps onto the lunar surface

This page top: LM Antares with MET tracks reflecting the sunlight

This page bottom: (L) Kittyhawk seen from Antares in lunar orbit; (R) Agtive Seismic Experiment grenade launcher

(All photos NASA)



Ed Mitchell operates the "Thumper", part of the Active Seismic Experiment, during the first Apollo 14 Moonwalk (NASA)

First Moonwalk

The first of Apollo 14's two Moonwalks started several hours later – a little late because of a problem the communications system in Shepard's suit. Shepard's first words as he stepped off Antares' footpad were "It's been a long way, but we're here," – a reference to both the distance travelled, and what it took Shepard to get back on flight status. Mitchell joined him minutes later, and the crew set about their tasks.

A new piece of equipment made its first and only flight on Apollo 14: a two-wheeled hand-pulled cart called the Modular Equipment Transporter (MET) – nicknamed "Shepard's rickshaw" – that carried tools and equipment the astronauts would use during their two Moonwalks.

One of the first jobs was to set up the S-band antenna. This antenna, which looked like an inverted lawn umbrella, wouldn't stand up properly, and fixing this was one of several problems that caused them to fall behind the tight timeline. Moon dust proved a problem, too, clinging to the astronauts' suits and equipment. The main task for this first Moonwalk was to set up the ALSEP (Apollo Lunar Surface Experiments Package). Problems cropped up here also, including a stiff cable on one of the experiment packages (the Cold Cathode Ion Gauge, or CCIG) that caused it to repeatedly fall over.

One of the more interesting experiments was the Active Seismic Experiment. This was a two-part experiment. One part comprised a grenade launcher (really!) that would be activated after the astronauts had left the Moon. The grenade explosions would be registered by the ALSEP seismometer to provide details on the lunar interior. The second part of the experiment was conducted during this first excursion. First, a long cable was unfurled, to which were attached several geophones (small seismometers) at regular intervals. Mitchell then walked along this cable with a device called the "thumper", which contained 21 small charges which were fired off at regular intervals to pound the surface, the vibrations being picked up by the geophones. This was successfully completed, though some of the 21 charges failed to fire. The data showed the Fra Mauro regolith to be 8.5 metres deep, consistent with pre-flight estimates.

In the time remaining during the first walk the crew collected 20.49 kg of soil and rock samples. Total time on the surface was 4 hours, 47 minutes.

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Back here in New Zealand, listening to this first Moonwalk was rather frustrating. The National Programme only aired two small segments of the walk. These were in the wee small hours of Saturday morning. I managed to wake up in time to listen to Shepard step onto the surface, but after a short time the radio went back to its normal programme and said that another segment of the Moonwalk would be on later. Miraculously, I managed to wake up just in time for this! The crew were setting up the ALSEP and having the problems with steadying the CCIG mentioned above. This was the end of the radio coverage of the Moonwalks – they didn't carry any of the second walk the following night, to my great annoyance and disappointment. – DM

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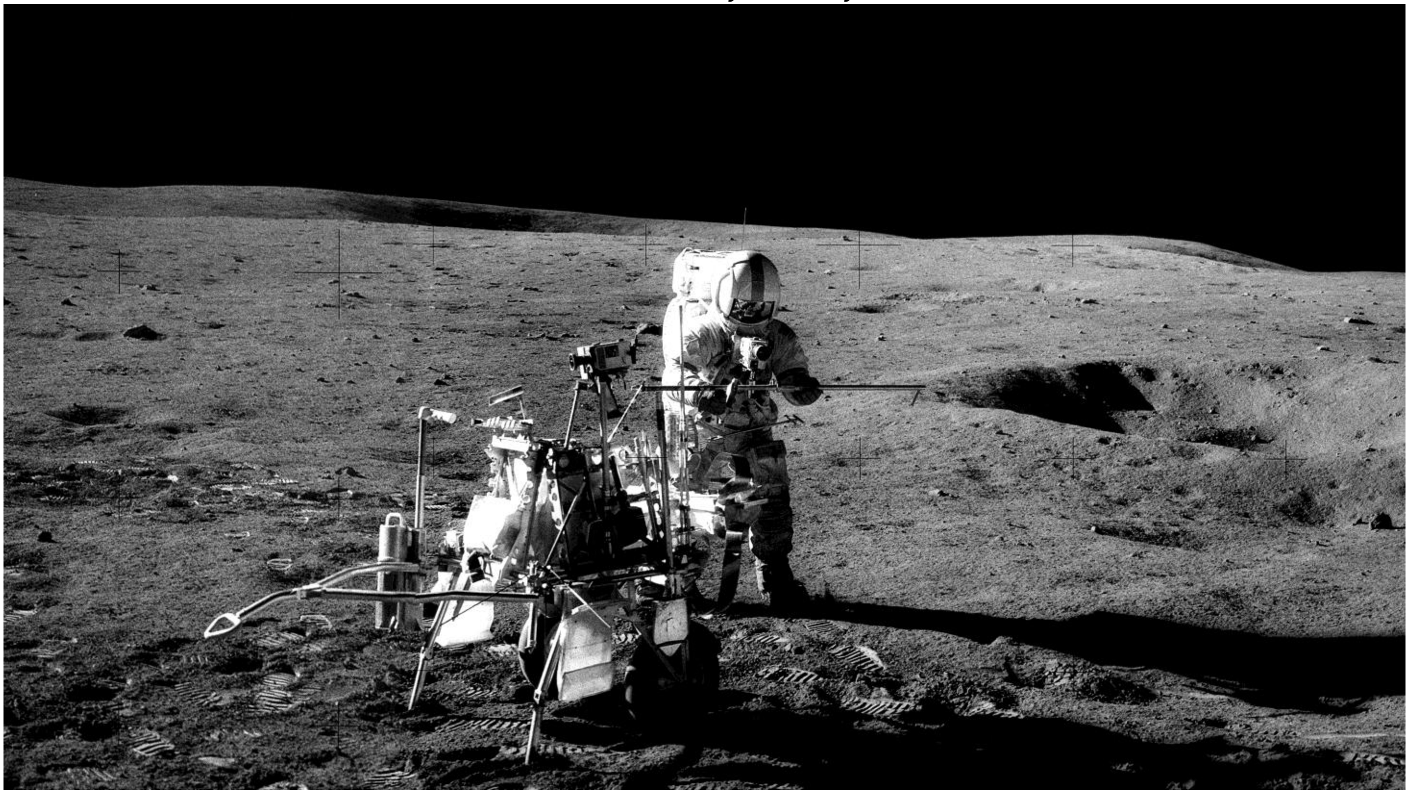
The climb to Cone Crater

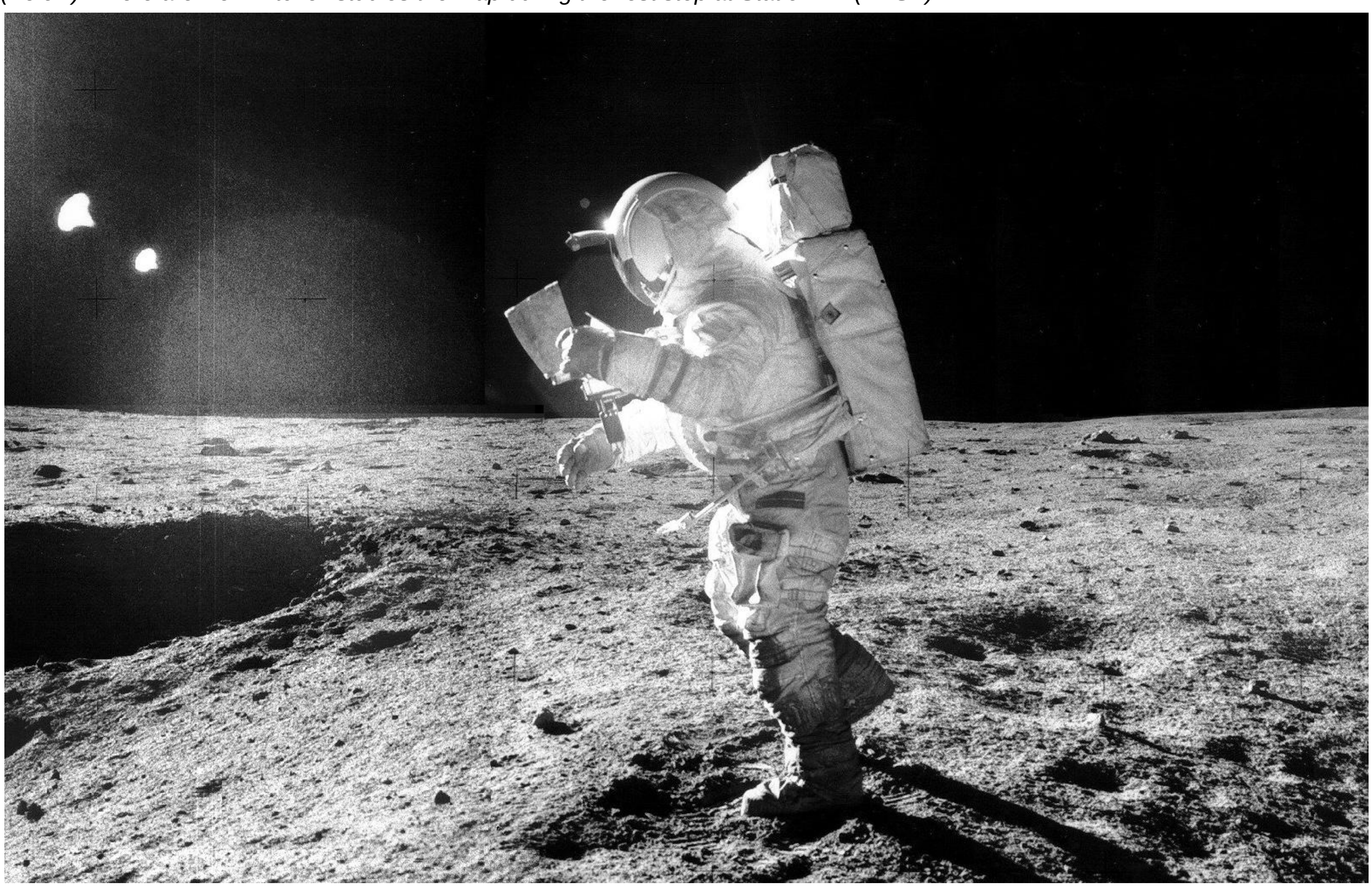
In contrast to a late start for the first Moonwalk, the second excursion started two hours early, as the crew were eager to get to work, and in any case hadn't got much sleep. The objective of the second walk was to walk to the rim of Cone Crater, located on a low ridge about a thousand metres northeast of the landing site. The crew hoped to gather samples from the lunar interior that were blasted out when Cone Crater formed from a meteorite impact.

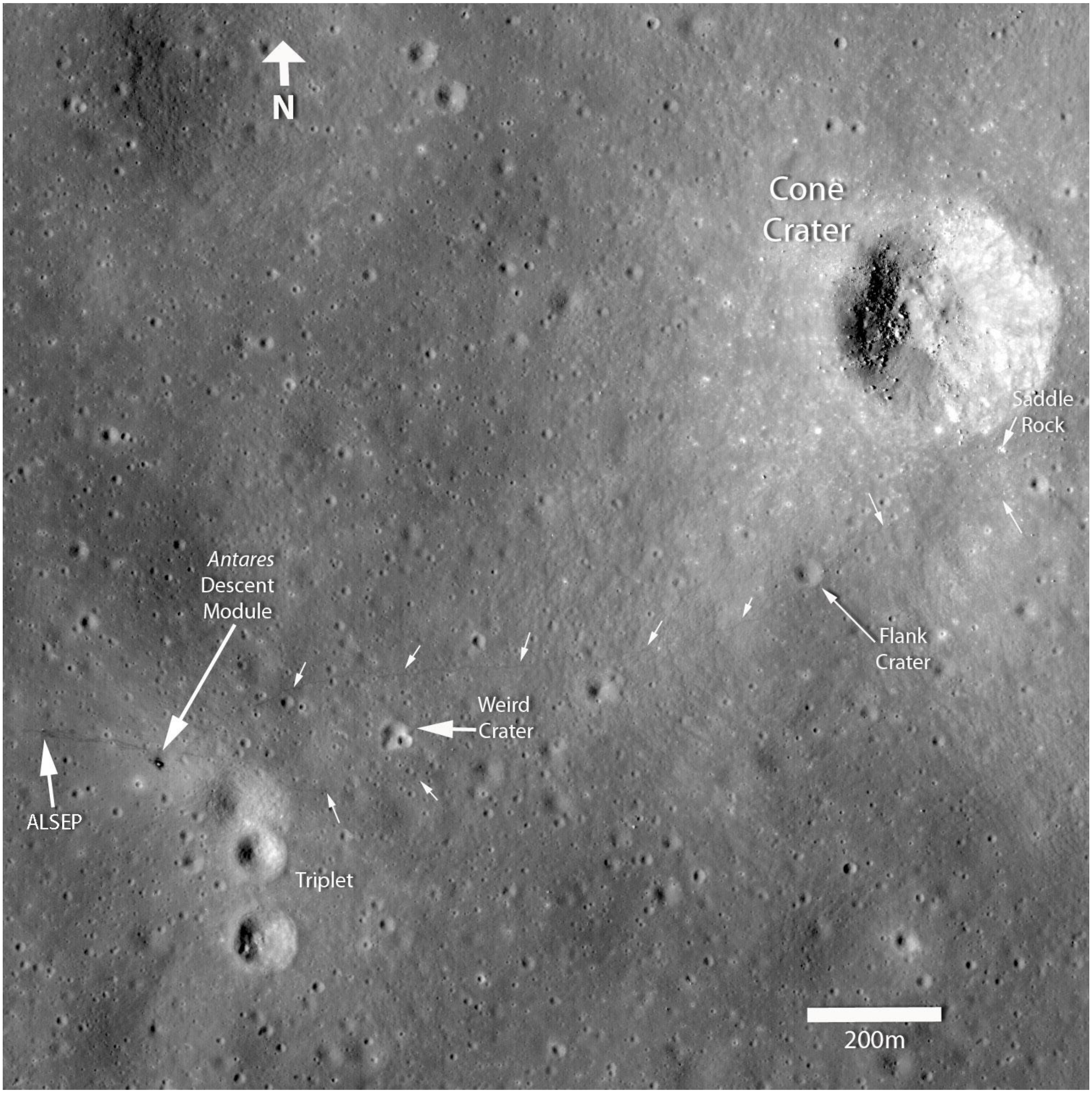
The climb to Cone Crater was not expected to be difficult, but the MET bounced around a lot on the uneven terrain, forcing Shepard and Mitchell to adopt a slower gait. Two preselected sampling stops (A and B) were scheduled, but the rolling terrain made it difficult for the astronauts to know exactly where they were, despite carrying maps. At the first stop, the astronauts spent 35 minutes, longer than planned, taking measurements and collecting samples. When they set off again they thought they were already a third of the way to Cone, but in fact they



(Above) Alan Shepard, standing next to the Modular Equipment Transporter, assembles a core sample tube at Station A, on the way to Cone Crater (NASA)

(Below) Where are we? Mitchell studies the map during the rest stop at Station B1 (NASA)





A recent Lunar Reconnaissance Orbiter view of the Apollo 14 landing site. The descent stage of the LM Antares can be clearly seen, along with the tracks of the astronauts and the MET. The white arrows mark the path Shepard and Mitchell took during their two Moonwalks. The feature named Saddle Rock (see also opposite page), near the rim of Cone Crater, shows how frustratingly close the astronauts came to their objective. (NASA)

were only 175 metres from *Antares*: Cone Crater was still a kilometer away.

Their next task was to find site B, but again the terrain confused them. The site was supposed to be in a field of boulders near a 20-metre crater, but they weren't sure that the site they stopped at was the right one. It later turned out that it was closer to where they should have stopped for site A, and was only about 200 metres from their first stop. Lunar field geology was still in its infancy, and everyone was on a learning curve.

When they left site B Shepard and Mitchell were about 15 minutes behind the timeline. As they climbed higher they entered Cone's ejecta blanket, and the nature of the terrain changed: more rocks and coarser regolith, and the overall surface became much rougher, making the going difficult. The slope increased to 10 degrees, and the astronauts could clearly be heard huffing and puffing as they climbed the ridge. At one point the astronauts had to physically lift and carry the MET over the rocks.

They paused for a rest stop which they thought was north of a crater called Flank, which would indicate they were nearing their goal. In fact, they were only about 700 metres east of the LM, near where they should have stopped for the site B sample. (The rest stop was subsequently named B1.)

Part of a large boulder named Saddle Rock, at Station C1 – the closest Shepard and Mitchell came to the rim of Cone Crater, which unbeknownst to them was only a few metres away (NASA)

Moving on about 150 metres from the rest point, Shepard and Mitchell found a partially buried boulder with a fillet of eroded material. The site was later named B2. Another ridge loomed ahead, beyond which the astronauts were sure they would find Cone Crater. But what they saw was yet another ridge. “Oh boy, we sure got fooled on that one,” said Mitchell.

At about this point, two hours into the Moonwalk, Shepard and Mitchell were not sure where they were. There was a nearby field of blocks, and Shepard suggested they sample those rather than proceed to the next ridge, which he estimated to be about 30 minutes away. Mitchell was frustrated. “Oh, let’s give it a whirl,” he said. “Gee whizz. We can’t stop without looking into Cone Crater!” To which Shepard replied, “I think we’ll waste a lot of time travelling and not much documenting.” He was sure that the boulder field he was looking at was ejecta from Cone. – and by now they were 25 minutes behind the timeline. Shepard decided to carry on a little further, however, and Capcom Fred Haise, back in Mission Control, notified the crew that they had a 30-minute extension.

The crew began sampling the boulder field, but soon used up their 30-minute extension. Moving off the ridge, they were now heading back to *Antares*. The site they left, called C-Prime, was the closest they came to the lip of Cone Crater. Has they been able to stay longer at the site, they would almost certainly have found the rim of the crater. However, they had, essentially, completed their sampling objectives at Cone.

Following a couple more stops on the way back, Shepard and Mitchell arrived back at *Antares*, having made quicker progress coming down than they did going up. Before ending the 4-hr, 34 min Moonwalk, Shepard had one more thing he wanted to do. Taking the handle from the contingency sampling tool in one hand, Shepard fitted the head of a six-iron golf club to it. He then placed a golf ball on the surface. “I’m going to try a little sand trap shot,“ he chuckled. His first swing missed, the second only moved the ball a short distance. Producing a second ball, Shepard took another swing and connected, sending the golf ball off on a low trajectory. “Miles and miles and miles,” said Shepard. (In fact, it was only 15 metres or so). Finally, Shepard removed the six-iron and tossed the handle like a javelin, which landed near the ball. “Outstanding!” Shepard exclaimed. “Right in the middle of the crater.”

Farewell to Fra Mauro

With their precious cargo of Moon samples (42.2 kg in all) safely stowed aboard *Antares*, Shepard and Mitchell settled down to a well-earned rest. Next day was departure day. Thirty-three hours and 30 minutes after they arrived, Shepard and Mitchell fired *Antares*’ ascent stage engine and left the Fra Mauro highlands, For the first time on an Apollo landing, Apollo 14 used a direct-insertion trajectory that led to a rendezvous with Roosa and Kittyhawk on the first orbit, about two hours after leaving the Moon (previous missions took 4-5 hours to rendezvous).

“What are you doing way down there, O fearless one?” called Roosa as he spied Antares approach Kittyhawk. While Shepard and Mitchell had been exploring the surface, Roosa had been busy with his own set of observations, which among other things included photography of future Apollo landing sites such as the Descartes region, selected for Apollo 16.

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This event occurred on the morning of Sunday 7 February (NZT), and fortunately the radio did carry the launch and rendezvous! This was the last transmission I got to hear live, however. – DM

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Homeward bound

With the crew reunited, Kittyhawk burned out of lunar orbit a few hours later and set a course for Earth. Antares’ ascent stage was sent to crash into the Moon, with the seismic signal detected now by two seismometers. The return trip was uneventful, but they crew’s scientific work was not over yet. Aboard Kittyhawk were a series out four engineering experiments designed to test the behavior of fluids and gases in microgravity – paving the way for future, more extensive experiments that would be conducted aboard the Space Shuttle and space stations such as Skylab, Salyut, Mir and ISS.

Ed Mitchell carried out a few private experiments of his own regarding ESP (extra-sensory perception), in collaboration with a colleague back on Earth, but the results were, apparently, inconclusive.

On 9 February, Kittyhawk jettisoned its Service Module and streaked through the earth’s atmosphere above the Pacific Ocean (re-entry was reputedly seen from Auckland, occurring around 9 a.m. NZT), splashing down within sight of the recovery carrier, *USS New Orleans*.

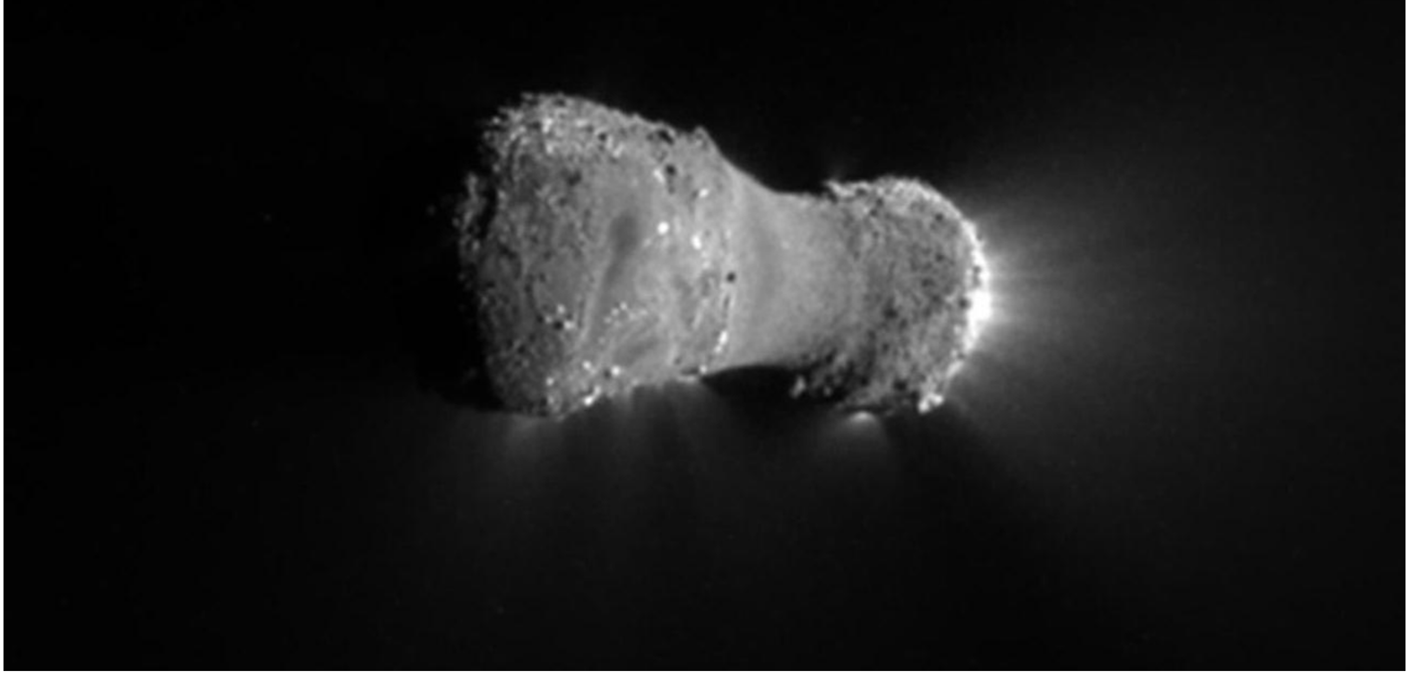
Only three more Apollo landings remained, but these would be the most spectacular of all, with three-day lunar surface stays and mobility aided by an electric-powered Moon buggy.

Epilogue

None of the Apollo 14 crew flew into space again. Alan Shepard from NASA and the US Navy in 1974, having attained the rank of Rear-Admiral. He died from leukemia on 21 July 1998. Stu Roosa left NASA in 1976 and went into business, and died on 12 December 1994 of complications from pancreatitis. Ed Mitchell left NASA in October 1972 to continue his interests in psychic activities, founding the Institute for Noetic Sciences, of which he is Chairman.

EPOXI sees cosmic snowstorm at Hartley 2

- NASA



This close-up view of comet Hartley 2 was taken as NASA's EPOXI mission approached the comet on 4 November 2010. The spacecraft's Medium-Resolution Instrument snapped the picture from a distance of 816 km. The sun is to the right. The comet's nucleus, or main body, is approximately 2 km long and .4 km at the "neck," or most narrow portion. Jets can be seen streaming out of the nucleus. (NASA/JPL-Caltech/UMD)

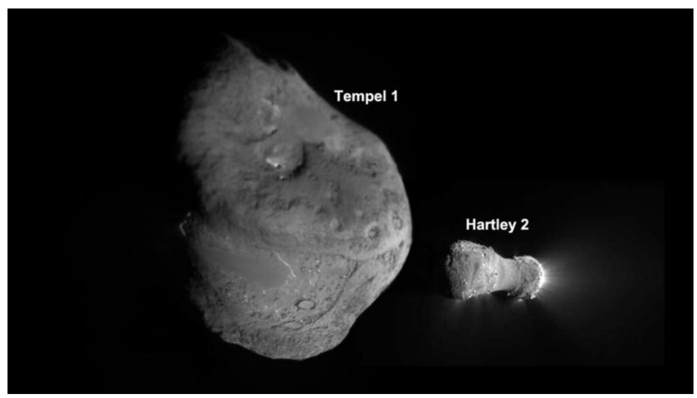
NASA's EPOXI mission spacecraft successfully flew past comet Hartley 2 at 7 a.m. PDT (10 a.m. EDT) Thursday 4 November 2010. The mission provided the first images clear enough for scientists to link jets of dust and gas with specific surface features. NASA and other scientists have begun to analyze the images. The EPOXI mission spacecraft revealed a cometary snow storm created by carbon dioxide jets spewing out tons of golf-ball to basketball-sized fluffy ice particles from the peanut-shaped comet's rocky ends. At the same time, a different process was causing water vapor to escape from the comet's smooth mid-section. This information sheds new light on the nature of comets and even planets.

Scientists compared the new data to data from a comet the spacecraft previously visited that was somewhat different from Hartley 2. In 2005, the spacecraft successfully released an impactor into the path of comet Tempel 1, while observing it during a flyby.

"This is the first time we've ever seen individual chunks of ice in the cloud around a comet or jets definitively powered by carbon dioxide gas," said Michael A'Hearn, principal investigator for the spacecraft at the University of Maryland. "We looked for, but didn't see, such ice particles around comet Tempel 1."

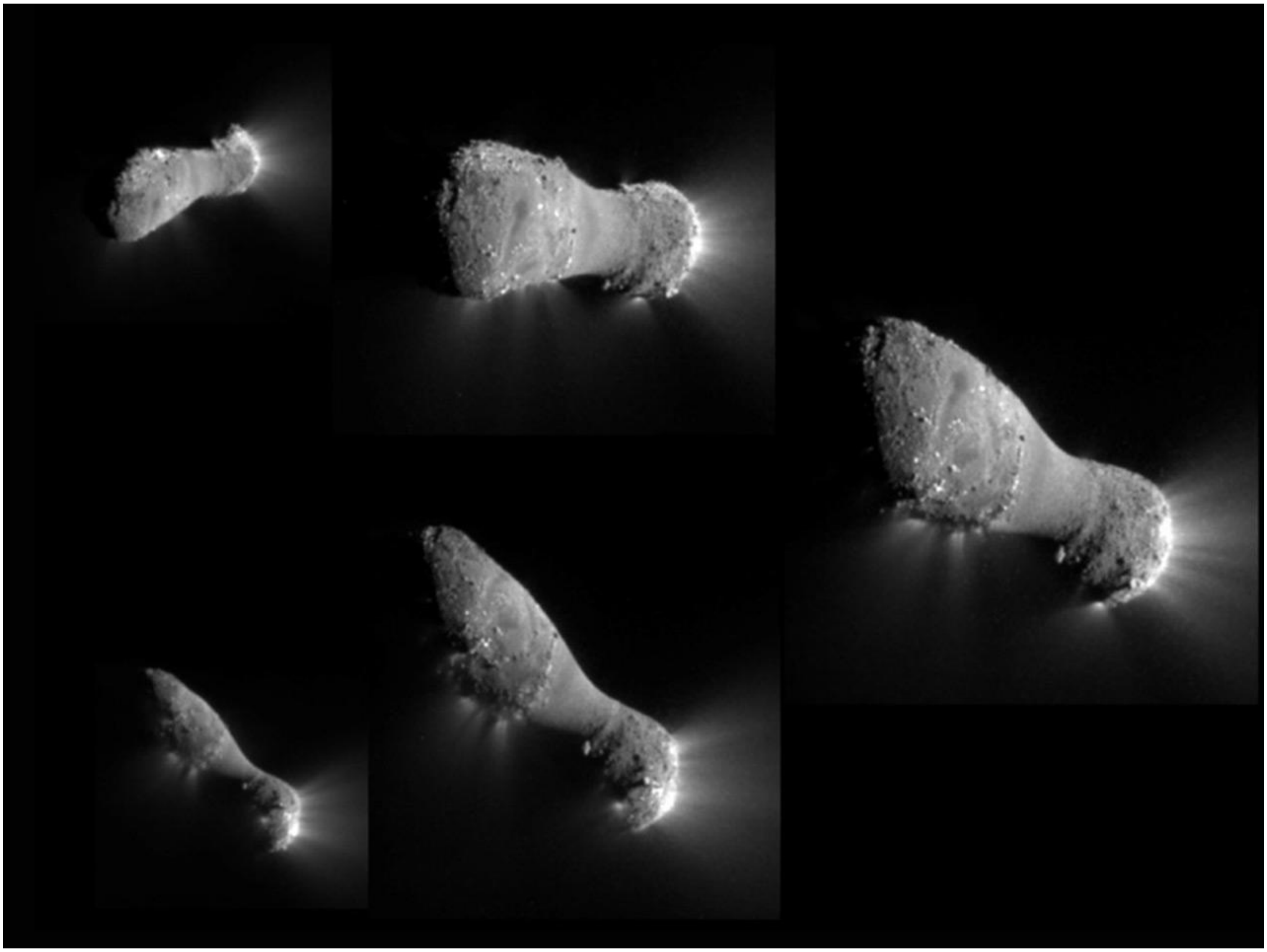
The new findings show Hartley 2 acts differently than Tempel 1 or the three other comets with nuclei imaged by spacecraft. Carbon dioxide appears to be a key to understanding Hartley 2 and explains why the smooth and rough areas scientists saw respond differently to solar heating, and have different mechanisms by which water escapes from the comet's interior.

"When we first saw all the specks surrounding the nucleus, our mouths dropped," said Pete Schultz, EPOXI mission co-investigator at Brown University. "Stereo images reveal there are snowballs in front and behind the nucleus, making it look like a scene in one of those crystal snow globes."



This image shows the nuclei of comets Tempel 1 and Hartley 2, as imaged by NASA's Deep Impact spacecraft, which continued as an extended mission known as EPOXI. Tempel 1 is five times larger than Hartley 2. Visible jets are easily seen in images of Hartley 2, but required extensive processing to be seen in images of Tempel 1. Tempel 1 is 7.6 km in the longest dimension. Hartley 2 is 2.2 km long. (NASA/JPL-Caltech/UMD)

Data show the smooth area of comet Hartley 2 looks and behaves like most of the surface of comet Tempel 1, with water evaporating below the surface and percolating out through the dust. However, the rough areas of Hartley 2, with carbon dioxide jets spraying out ice particles, are very different. "The carbon dioxide jets blast out water ice from specific locations in the rough areas resulting in a cloud of ice and snow," said Jessica Sunshine, EPOXI deputy principal investigator at the University of Maryland. "Underneath the smooth middle area, water ice



This image montage shows comet Hartley 2 as the EPOXI mission approached and flew under the comet. The images progress in time clockwise, starting at the top left. The image was taken by EPOXI's Medium-Resolution Instrument on 4 November 2010. The sun is to the right. (NASA/JPL-Caltech/UMD)

turns into water vapor that flows through the porous material, with the result that close to the comet in this area we see a lot of water vapor."

Engineers at NASA's Jet Propulsion Laboratory in Pasadena, Calif., have been looking for signs ice particles peppered the spacecraft. So far they found nine times when particles, estimated to weigh slightly less than the mass of a snowflake, might have hit the spacecraft but did not damage it. "The EPOXI mission spacecraft sailed through Hartley 2's ice flurries in fine working order and continues to take images as planned of this amazing comet," said Tim Larson, EPOXI project manager at JPL.

Scientists will need more detailed analysis to determine how long this snow storm has been active, and whether the differences in activity between the middle and ends of the comet are the result of how it formed some 4.5 billion years ago or are because of more recent evolutionary effects.

EPOXI is a combination of the names for the mission's two components: the Extrasolar Planet Observations and Characterization (EPOCh), and the flyby of comet Hartley 2, called the Deep Impact Extended Investigation (DIXI).

This image from the High-Resolution Instrument on NASA's EPOXI mission spacecraft shows part of the nucleus of comet Hartley 2. The sun is illuminating the nucleus from the right. A distinct cloud of individual particles is visible. (NASA/JPL-Caltech/UMD)

Curiosity's science payload takes shape

- NASA

Artist's impression of the Mars Science Laboratory Curiosity on the surface of Mars. It is due to be launched late in 2011 (NASA/JPL)

NASA's next Mars rover, the car-sized Curiosity Mars Science Laboratory, is nearing completion at the Jet Propulsion Laboratory in California, for launch during a window running from 25 November to 18 December this year. Curiosity will reach Mars in August 2012, and is planned to operate for at least two years. This articles focuses on three of the science instruments that Curiosity will carry to the Martian surface.

Mars rover will check for ingredients of life

Paul Mahaffy, the scientist in charge of the largest instrument on NASA's next Mars rover, watched through glass as clean-room workers installed it into the rover. The specific work planned for this instrument on Mars requires more all-covering protective garb for these specialized workers than was needed for the building of NASA's earlier Mars rovers.

The instrument is Sample Analysis at Mars, or SAM, built by NASA's Goddard Space Flight Center, Greenbelt, Md. At the carefully selected landing site for the Mars rover named Curiosity, one of SAM's key jobs will be to check for carbon-containing compounds called organic molecules, which are among the building blocks of life on Earth. The clean-room suits worn by Curiosity's builders at NASA's Jet Propulsion Laboratory, Pasadena, Calif., are just part of the care being taken to keep biological material from Earth from showing up in results from SAM.

Organic chemicals consist of carbon and hydrogen and, in many cases, additional elements. They can exist without life, but life as we know it cannot exist without them. SAM can detect a fainter trace of organics and identify a wider variety of them than any instrument yet sent to Mars. It also can provide information about other ingredients of life and clues to past environments.

Researchers will use SAM and nine other science instruments on Curiosity to study whether one of the most intriguing areas on Mars has offered environmental conditions favorable for life and favorable for preserving evidence about whether life has ever existed there.

"If we don't find any organics, that's useful information," said Mahaffy, of NASA's Goddard Space Flight Center. "That would mean the best place to look for evidence about life on Mars may not be near the surface. It may push us to look deeper." It would also aid understanding of the environmental conditions that remove organics.

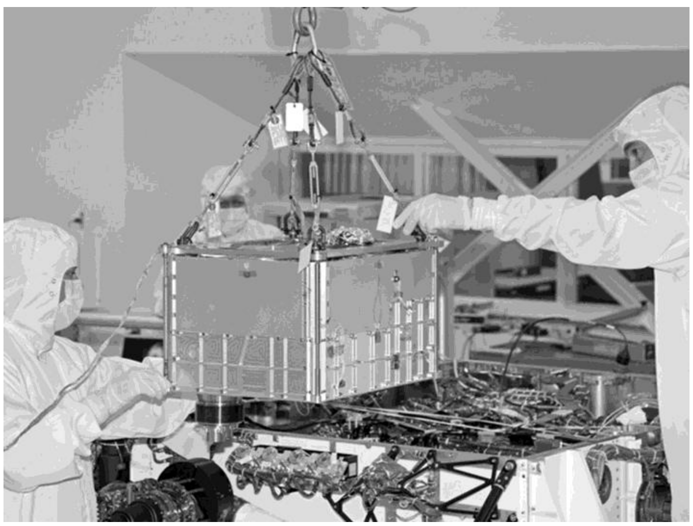
"If we do find detectable organics, that would be an encouraging sign that the immediate environment in the rocks we're sampling is preserving these clues," he said. "Then we would use the tools we have to try to determine where the organics may have come from." Organics delivered by meteorites without involvement of biology come with more random chemical structures than the patterns seen in mixtures of organic chemicals produced by organisms.

Mahaffy paused in describing what SAM will do on Mars while engineers and technicians lowered the instrument into its position inside Curiosity this month. A veteran of using earlier spacecraft instruments to study planetary atmospheres, he has coordinated work of hundreds of people in several states and Europe to develop, build and test SAM after NASA selected his team's proposal for it in 2004. "It has been a long haul getting to this point," he said. "We've taken a set of experiments that would occupy a good portion of a room on Earth and put them into that box the size of a microwave oven."

SAM has three laboratory tools for analyzing chemistry. The tools will examine gases from the Martian atmosphere, as well as gases that ovens and solvents pull from powdered rock and soil samples. Curiosity's robotic arm will deliver the powdered samples to an inlet funnel. SAM's ovens will heat most samples to about 1,000 degrees Celsius.

One tool, a mass spectrometer, identifies gases by the molecular weight and electrical charge of their ionized states. It will check for several elements important for life as we know it, including nitrogen, phosphorous, sulfur, oxygen and carbon. Another tool, a laser spectrometer, uses absorption of light at specific wavelengths to measure concentrations of selected chemicals, such as methane and water vapor. It also identifies the proportions of different isotopes in those gases. Isotopes are variants of the same element with different atomic weights, such as carbon-13 and carbon-12, or oxygen-18 and oxygen-16. Ratios of isotopes can be signatures of planetary processes. For example, Mars once had a much denser atmosphere than it does today, and if the loss occurred at the top of the atmosphere, the process would favor increased concentration of heavier isotopes in the retained, modern atmosphere.

Methane is an organic molecule. Observations from Mars orbit and from Earth in recent years have suggested transient methane in Mars' atmosphere, which would mean methane is being actively added and subtracted at Mars. With SAM's laser spectrometer, researchers will check to confirm whether methane is present, monitor any changes in concentration, and look for clues about whether Mars methane is produced by biological activity or by processes that do not require life. JPL provided SAM's laser spectrometer.



Techncians and engineers inside a clean room at the Jet Propulsion Laboratory, Pasadena, Calif., prepare to install SAM into the mission's Mars rover, Curiosity. (NASA/JPL-Caltech)

SAM's third analytical tool, a gas chromatograph, separates different gases from a mixture to aid identification. It does some identification itself and also feeds the separated fractions to the mass spectrometer and the laser spectrometer. France's space agency, Centre National d'Etudes Spatiales, provided support to the French researchers who developed SAM's gas chromatograph.

NASA's investigation of organics on Mars began with the twin Viking landers in 1976. Science goals of more recent Mars missions have tracked a "follow the water" theme, finding multiple lines of evidence for liquid water -- another prerequisite for life -- in Mars' past. The Mars Science Laboratory mission will seek more information about those wet environments, while the capabilities of its SAM instrument add a trailblazing "follow the carbon" aspect and information about how well ancient environments may be preserved.

The original reports from Viking came up negative for organics. How, then, might Curiosity find any? Mahaffy describes three possibilities.

The first is about locations. Mars is diverse, not uniform. Copious information gained from Mars orbiters in recent years is enabling the choice of a landing site with favorable attributes, such as exposures of clay and sulfate minerals good at entrapping organic chemicals. Mobility helps too, especially with the aid of high-resolution geologic mapping generated from orbital observations. The stationary Viking landers could examine only what their arms could reach. Curiosity can use mapped geologic context as a guide in its mobile search for organics and other clues about habitable environments. Additionally, SAM will be able to analyze samples from interiors of rocks drilled into by Curiosity, rather than being restricted to soil samples, as Viking was.

Second, SAM has improved sensitivity, with a capability to detect less than one part-per-billion of an organic compound, over a wider mass range of molecules and after heating samples to a higher temperature.

Third, a lower-heat method using solvents to pull organics from some SAM samples can check a hypothesis that a reactive chemical recently discovered in Martian soil may have masked organics in soil samples baked during Viking tests.

The lower-heat process also allows searching for specific classes of organics with known importance to life on Earth. For example, it can identify amino acids, the chain links of proteins. Other clues from SAM could also be hints about whether organics on Mars -- if detected at all -- come from biological processes or without biology, such as from meteorites. Certain carbon-isotope ratios in organics compared with the ratio in Mars' atmosphere could suggest meteorite origin. Patterns in the number of carbon atoms in organic molecules could be a clue. Researchers will check for a mixture of organics with chains of carbon atoms to see if the mix is predominated either by chains with an even number of carbon atoms or with an odd number. That kind of pattern, rather than a random blend, would be typical of biological assembly of carbon chains from repetitious subunits.

"Even if we see a signature such as mostly even-numbered chains in a mix of organics, we would be hesitant to make any definitive statements about life, but that would certainly indicate that our landing site would be a good place to come back to," Mahaffy said. A future mission could bring a sample back to Earth for more extensive analysis with all the methods available on Earth.

Curiosity to zap rocks with laser

A rock-zapping laser instrument on the Curiosity rover has roots in a demonstration that Roger Wiens saw 13 years ago in a colleague's room at Los Alamos National Laboratory in New Mexico. The Chemistry and Camera (ChemCam) instrument on the rover Curiosity can hit rocks with a laser powerful enough to excite a pinhead-size spot into a glowing, ionized gas. ChemCam then observes the flash through a telescope and analyzes the spectrum of light to identify the chemical elements in the target.

That information about rocks or patches of soil up to about 7 metres away will help the rover team survey the rover's surroundings and choose which targets to drill into, or scoop up, for additional analysis by other instruments on Curiosity. With the 10 science instruments on the rover, the team will assess whether any environments in the landing area have been favorable for microbial life and for preserving evidence about whether life existed.

Wiens, a geochemist with the U.S. Department of Energy's Los Alamos National Laboratory, serves as ChemCam's principal investigator. An American and French team that he leads proposed the instrument during NASA's 2004 open competition for participation in the Mars Science Laboratory project, whose rover has since been named Curiosity.

In 1997, while working on an idea for using lasers to investigate the moon, Wiens visited a chemistry laboratory building where a colleague, Dave Cremers, had been experimenting with a different laser technique. Cremers set up a cigar-size laser powered by a little 9-volt radio battery and pointed at a rock across the room. "The room was well used. Every flat surface was covered with instruments, lenses or optical mounts," Wiens recalls. "The filing cabinets looked like they had a bad case of acne. I found out later that they were used for laser target practice."

Cremers pressed a button. An invisible beam from the laser set off a flash on a rock across the room. The flash was ionized gas, or plasma, generated by the energy from the laser exciting atoms in the rock. A spectrometer pointed at the glowing plasma recorded the intensity of light at different wavelengths for determining the rock's atomic ingredients.

Researchers have used lasers for inducing plasmas for decades. What impressed Wiens in this demonstration was the capability to do it with such a low-voltage power source and compact hardware. Using this technology for a robot on another planet seemed feasible. From that point, more than a decade of international development and testing resulted in ChemCam being installed on Curiosity in September 2010.

The international collaboration came about in 2001 when Wiens introduced a former Los Alamos post-doctoral researcher, Sylvestre Maurice, to the project. The core technology of ChemCam, laser-induced breakdown spectroscopy, had been used for years in France as well as in America, but it was still unknown to space scientists there. "The technique is both flashy and very compelling scientifically, and the reviewers in France really liked that combination," Maurice said. A French team was formed, and work on a new laser began.

"The trick is very short bursts of the laser," Wiens said. "You really dump a lot of energy onto a small spot -- megawatts per square millimeter -- but just for a few nanoseconds."

The pinhead-size spot hit by ChemCam's laser gets as much power focused on it as a million light bulbs, for five one-billionths of a second. Light from the resulting flash comes back to ChemCam through the instrument's telescope, mounted beside the laser high on the rover's camera mast. The telescope directs the light down an optical fiber to three spectrometers inside the rover. The spectrometers record intensity at 6,144 different wavelengths of ultraviolet, visible and infrared light. Different chemical elements in the target emit light at different wavelengths.

If the rock has a coating of dust or a weathered rind, multiple shots from the laser can remove those layers to provide a clear shot to the rock's interior composition. "We can see what the progression of composition looks like as we get a little bit deeper with each shot," Wiens said.

Earlier Mars rover missions have lacked a way to identify some of the lighter elements, such as carbon, oxygen, hydrogen, lithium and boron, which can be clues to past environmental conditions in which the rock was formed or altered. After NASA's Mars Exploration Rover Spirit examined an outcrop called "Comanche" in 2005, it took years of analyzing indirect evidence before the team could confidently infer the presence of carbon in the rock. A single observation with ChemCam could detect carbon directly.

ChemCam will be able to interrogate multiple targets the same day, gaining information for the rover team's careful selection of where to drill or scoop samples for laboratory investigations that will take multiple days per target. It can also check the composition of targets inaccessible to the rover's other instruments, such as rock faces beyond the reach of Curiosity's arm.

The instrument's telescope doubles as the optics for the camera part of ChemCam, which records images on a one-megapixel detector. The telescopic camera will show context of the spots hit with the laser and can also be used independently of the laser.

The French half of the ChemCam team, headed by Maurice and funded by France's national space agency, provided the instrument's laser and telescope. Maurice is a spectroscopy expert with the Centre d'Etude Spatiale des Rayonnements, in Toulouse, France. Los Alamos National Laboratory supplied the spectrometers and data processor inside the rover. The optical design of the spectrometers came from Ocean Optics, Dunedin, Fla. The ChemCam team includes experts in mineralogy, geology, astrobiology and other fields, with some members also on other Curiosity instrument teams.

Camera on Curiosity’s arm will magnify clues in rocks

Curiosity will wield an arm-mounted magnifying camera similar to one on the Mars Rover Opportunity, which promptly demonstrated its importance for reading environmental history from rocks at its landing site in 2004. Within a few weeks after the landing, that camera at the end of Opportunity's arm revealed details of small spheres embedded in the rocks, hollows where crystals had dissolved, and fine layering shaped like smiles. These details all provided information about the site's wet past.

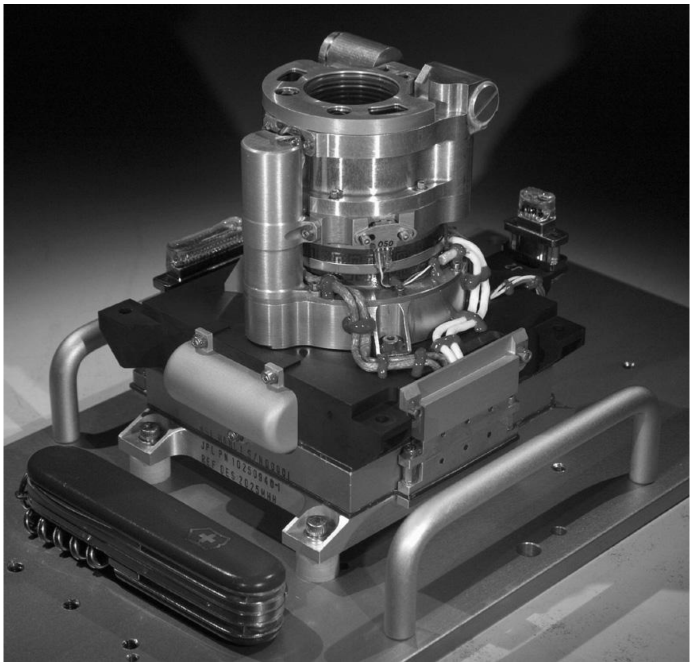
The camera installed on the end of Curiosity's arm this month is the Mars Hand Lens Imager, or MAHLI. Its work will include the same type of close-up inspections accomplished by the comparable camera on Opportunity, but MAHLI has significantly greater capabilities: full-color photography, adjustable focus, lights, and even video. Also, it sits on a longer arm, one that can hold MAHLI up higher than the cameras on the rover's mast. MAHLI will use those capabilities as one of 10 science instruments to study the area of Mars where NASA's Mars Science Laboratory mission lands Curiosity in August 2012.

The Mars Hand Lens Imager takes its name from the magnifying tool that every field geologist carries. Ken Edgett of Malin Space Science Systems, San Diego, is the principal investigator for the instrument. He said, "When you’re out in the field and you want to get a quick idea what minerals are in a rock, you pick up the rock in one hand and hold your hand lens in the other hand. You look through the lens at the colors, the crystals, the cleavage planes: features that help you diagnose what minerals you see.

"If it's a sedimentary rock, such as the sandstone you see at Arches National Park in Utah, or shale -- which is basically petrified mud -- like in the Painted Desert in Arizona, you use the hand lens not just to see what minerals are in it but also the sizes and shapes of the grains in the rock. You also look at the fine-scale layering in the rock to get an idea of the sequence of events. Sedimentary rocks record past events and environments."

While other instruments on Curiosity will provide more information about what minerals are in rocks, the Mars Hand Lens Imager will play an important role in reading the environmental history recorded in sedimentary rocks. The mission's science team will use the instruments to assess whether the selected landing area has had environmental conditions favorable for life and for preserving evidence about whether life existed.

Edgett led the preparation in early 2004 of a proposal to include MAHLI in the Mars Science Laboratory's payload. During those same months, the camera on Opportunity's arm –



The Mars Hand Lens Imager (MAHLI) camera will fly on NASA's Mars Science Laboratory mission, launching in late 2011. (NASA/JPL-Caltech/Malin Space Science Systems)

that mission's Microscopic Imager -- was demonstrating the potential value of a successor, and generating ideas for improvements. Opportunity's Microscopic Imager has a fixed focus. To get targets in focus, it always needs to be placed the same distance from the target, recording a view of an area 3 centimetres (across. To view a larger area, the camera takes multiple images, sometimes more than a dozen, each requiring a repositioning of Opportunity's arm.

"When I was writing the proposal, the Microscopic Imager took about 40 images for a mosaic of one rock," Edgett said. "That's where the idea came from to make the focus adjustable. With adjustable focus, the science team has more flexibility for trade-offs among the rover's resources, such as power, time, data storage and data downlink. For example, the camera could take one or two images from farther away to cover a larger area, then go in and sample selected parts in higher resolution from closer up."

MAHLI can focus on targets as close as about 21 millimetres and as distant as the horizon or farther. JPL's Ashwin Vasavada, deputy project scientist for the Mars Science Laboratory, said, "MAHLI is really a fully functional camera that happens to be on the end of the arm. The close-up capability is its specialty, but it will also be able to take images or videos from many viewpoints inaccessible to the cameras on the mast, such as up high, down low, under the rover and on the rover deck. Think of it like a hand-held camera with a macro lens, one that you could use for taking pictures of the Grand Canyon, of yourself, or of a bumblebee on a flower."

Edgett is looking forward to what the camera will reveal in rock textures. "Just like larger rocks in a river, grains of sand carried in a stream get rounded from bouncing around and colliding with each other," he said. "If you look at a sandstone with a hand lens and see rounded grains, that tells you they came from a distance. If they are more angular, they didn't come as far before they were deposited in the sediment that became the rock. Where an impact excavated a crater, particles of the material ejected from the crater would be very angular.

"When you're talking about ancient rocks as clues for assessing habitability," he continued, "you're talking about the environments the sediments were deposited in -- whether a lake, a desert, an ice field. Also, what cemented the particles together to become rocks, and what changes have affected the rock after the sediments were deposited? All these things are relevant to whether an environment was favorable for life and also whether it was favorable for preserving the record of that life. Earth is a planet teeming with life, but most rocks have not preserved ancient organisms; Mars will be even more challenging than Earth in this sense."

Edgett says he is eager to see an additional image from this camera besides the details of rock textures. With the arm extended upwards, the camera can look down at the rover for a dramatic self-portrait on Mars. But as for the most important image the Mars Hand Lens Imager will take: "That will be something that surprises us, something we're not expecting."

The Curiosity rover will use an innovative "skycrane" system to land on Mars. A rocket-powered carrier will lower the rover to the surface, as the craft is too big to use the airbag system previous rovers have used (NASA/JPL)

An infrared image from ESA's Herschel spacecraft shows rings of dust in the Andromeda Galaxy that trace gaseous reservoirs where new stars are forming and XMM-Newton's X-ray image shows stars approaching the ends of their lives. Both infrared and X-ray images convey information impossible to collect from the ground because these wavelengths are absorbed by Earth's atmosphere.)ESA/Herschel/PACS/SPIRE/J.Fritz, U.Gent/XMM-Newton/EPIC/W. Pietsch, MPE)