Liftoff
New Zealand's space exploration magazine

Issue 259
September-October 2010

Asteroid odyssey

- Hayabusa's troubled journey to Itokawa and back

Also inside:

- **Latest Mars findings**
- **Looking for lunar dust fountains**

Liftoff

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NZSA News and Notices

Auckland meetings

The next Auckland meetings are on **5 October** and **2 November** 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 new year (probably February). 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 2010 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: An artist's impression of Japan's Hayabusa spacecraft about to touch down on the surface of asteroid Itokawa in 2005 (JAXA) - *See page 10.*

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Editor's Corner

We're all familiar with the story of Apollo 13, and how NASA engineers struggled to get the crew of the crippled spacecraft back to Earth. Well, the Japanese space agency JAXA has now had a kind of Apollo 13 moment of its own. Luckily, human lives were not at risk on this occasion, but JAXA flight controllers deserve a huge round of applause for surmounting multiple failures to get their little asteroid sampling mission, Hayabusa, back to Earth. Read all about it on page 10. I reckon this is one of the space success stories of the decade, even if it turns out they didn't manage to get any asteroid samples (better luck next time – there is a follow-up mission in the works).

New discoveries from Mars keep coming thick and fast, and you'll find a whole bunch of them beginning on page 16. One of the most interesting concerns a finding from the Phoenix lander in 2008 that suggests the twin Viking landers of the mid-1970s may have found soil containing carbon-based chemical building blocks of life (but not life itself – there's a big difference!)

As I write this, the next space shuttle mission is being assembled at the Kennedy Space Center in Florida in preparation for its November launch. This will be the final mission for shuttle Discovery, a bittersweet moment for all concerned. Only one more shuttle flight is definitely scheduled after that, though NASA is pressing to add one final supply flight to the International Space Station in mid-2011. This will be up to Congress, however, so don't hold your breath.

Closer to home, as noted opposite, it seems likely that Wellington meetings will resume in the new year. I visited the new-look Carter Observatory recently (*very* flash – you won't recognize the place inside!), and they are keen for us to continue to be a part of the wider Carter community. There'll be more details in a future issue.

Finally, a reminder that subscriptions for next year are now due (we've been able to drop the rates this year, so there's at least one thing that's not going up in price from 1 October because of GST!)

-- *David Maclennan*

NASA selects investigations for first mission to encounter the Sun

NASA has begun development of a mission to visit and study the Sun closer than ever before. The unprecedented project, named Solar Probe Plus, is slated to launch no later than 2018. The small car-sized spacecraft will plunge directly into the Sun's atmosphere approximately four million miles from our star's surface. It will explore a region no other spacecraft ever has encountered. NASA has selected five science investigations that will unlock the Sun's biggest mysteries.

"The experiments selected for Solar Probe Plus are specifically designed to solve two key questions of solar physics -- why is the Sun's outer atmosphere so much hotter than the Sun's visible surface and what propels the solar wind that affects Earth and our solar system? " said Dick Fisher, director of NASA's Heliophysics Division in Washington. "We've been struggling with these questions for decades and this mission should finally provide those answers."

As the spacecraft approaches the Sun, its revolutionary carbon-composite heat shield must withstand temperatures exceeding 2550 degrees Fahrenheit and blasts of intense radiation. The spacecraft will have an up close and personal view of the Sun enabling scientists to better understand, characterize and forecast the radiation environment for future space explorers.

NASA invited researchers in 2009 to submit science proposals. Thirteen were reviewed by a panel of NASA and outside scientists. The total dollar amount for the five selected investigations is approximately $180 million for preliminary analysis, design, development and tests.

The selected proposals are:

Solar Wind Electrons Alphas and Protons Investigation: principal investigator, Justin C. Kasper, Smithsonian Astrophysical Observatory in Cambridge, Mass.

This investigation will specifically count the most abundant particles in the solar wind -- electrons, protons and helium ions -- and measure their properties. The investigation also is designed to catch some of the particles in a special cup for direct analysis.

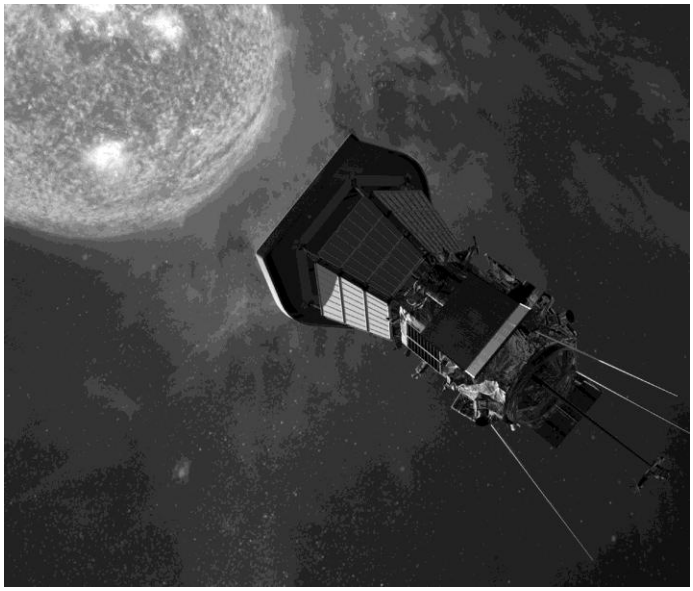
Wide-field Imager: principal investigator, Russell Howard, Naval Research Laboratory in Washington.

This telescope will make 3-D images of the Sun's corona, or atmosphere. The experiment actually
will see the solar wind and provide 3-D images of clouds and shocks as they approach and pass the spacecraft. This investigation complements instruments on the spacecraft providing direct measurements by imaging the plasma the other instruments sample.

Fields Experiment: principal investigator, Stuart Bale, University of California Space Sciences Laboratory in Berkeley, Calif.

This investigation will make direct measurements of electric and magnetic fields, radio emissions, and shock waves that course through the Sun's atmospheric plasma. The experiment also serves as a giant dust detector, registering voltage signatures when specks of space dust hit the spacecraft's antenna.

Integrated Science Investigation of the Sun: principal investigator, David McComas of the Southwest Research Institute in San Antonio.



The Solar Probe Plus spacecraft with solar panels folded into the shadows of its protective shield, gathers data on its approach to the Sun. (JHU/APL)

This investigation consists of two instruments that will take an inventory of elements in the Sun's atmosphere using a mass spectrometer to weigh and sort ions in the vicinity of the spacecraft.

Heliospheric Origins with Solar Probe Plus: principal investigator, Marco Velli of NASA's Jet Propulsion Laboratory in Pasadena, Calif.

Velli is the mission's observatory scientist, responsible for serving as a senior scientist on the science working group. He will provide an independent assessment of scientific performance and act as a community advocate for the mission.

"This project allows humanity's ingenuity to go where no spacecraft has ever gone before," said Lika Guhathakurta, Solar Probe Plus program scientist at NASA Headquarters, in Washington. "For the very first time, we'll be able to touch, taste and smell our Sun."

The Solar Probe Plus mission is part of NASA's Living with a Star Program. The program is designed to understand aspects of the Sun and Earth's space environment that affect life and society. The program is managed by NASA'S Goddard Space Flight Center in Greenbelt, Md., with oversight from NASA's Science Mission Directorate's Heliophysics Division. The Johns Hopkins University Applied Physics Laboratory in Laurel, Md., is the prime contractor for the spacecraft.

For more information about the Solar Probe Plus mission, visit: **http://solarprobe.gsfc.nasa.gov/**

Magnetospheric mission passes major milestone

The universe is still an arcane place that scientists know very little about, but a new NASA Solar Terrestrial Probe mission is going to shed light on one especially mysterious event called magnetic reconnection. It occurs when magnetic lines of force cross, cancel, and reconnect releasing magnetic energy in the form of heat and charged-particle kinetic energy. On the sun, magnetic reconnection causes solar flares more powerful than several atomic bombs combined. In Earth's atmosphere, magnetic reconnection dispenses magnetic storms and auroras, and in laboratories on Earth it can cause big problems in fusion reactors. Although the study of magnetic reconnection dates back to the 1950s and despite numerous scientific papers addressing this perplexing issue, scientists still cannot agree on one accepted model.

In 2014, NASA is scheduled to launch a satellite that will greatly increase our understanding of this phenomenon when it launches the Magnetospheric Multiscale (MMS) mission, a suite of four identical spacecraft that will study magnetic reconnection in the best possible laboratory – the Earth's magnetosphere. The spacecraft will obtain measurements necessary to test prevailing theories as to how reconnection is enabled and how it progresses.

Recently, NASA and members of an independent review board painstakingly reviewed every aspect of the MMS mission, and successfully completed the mission's critical design review. This technical review is held to ensure that a mission can proceed into fabrication, demonstration and test and can meet stated performance requirements, including cost, schedule, risk and other system constraints. According to MMS deputy project scientist Mark Adrian of NASA's Goddard Space Flight Center in Greenbelt, Md., "This is the last hurdle before the spacecraft and instrument teams begin to build actual flight hardware."

MMS was approved for implementation in June 2009 following a successful Preliminary Design Review in May 2009. Dr. James L. Burch of the Southwest Research Institute in San Antonio, Texas, will lead the MMS science team. According to Burch, "Magnetic reconnection is a fundamental physical process that occurs throughout the universe," says Burch. "MMS will enable us to study this dynamic process in the near-Earth space environment, where it transfers energy from the solar wind to the magnetosphere and drives disturbances known as space weather."

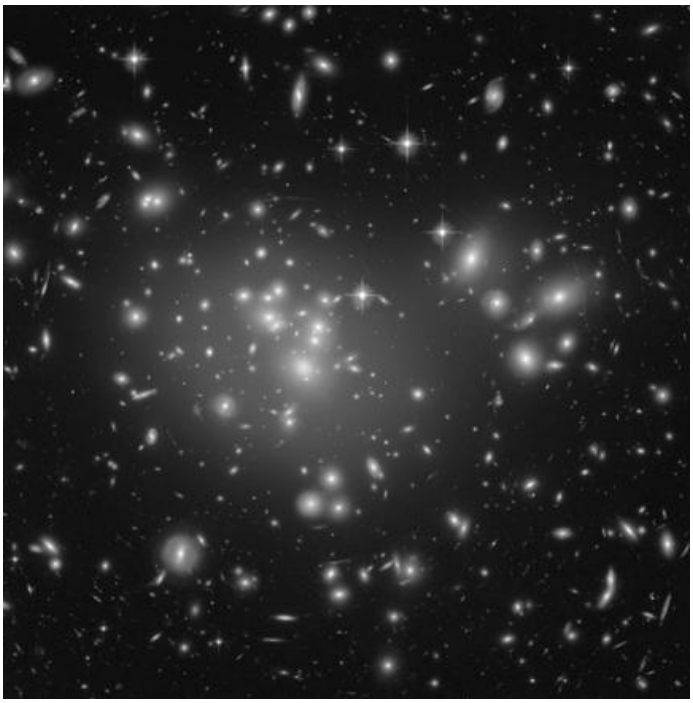
Goddard is the lead Center for the mission. Engineers there will perform the required environmental testing, build the spacecraft and integrate all four sets of instruments into the MMS satellites, support launch vehicle integration and operations, and develop the Mission Operations Center which to monitor and control the spacecraft.

MMS will carry identical suites of plasma analyzers, energetic particle detectors, magnetometers, and electric field instruments as well as a device to prevent spacecraft charging from interfering with the highly sensitive measurements required in and around the diffusion regions. Scientists and engineers at Goddard have designed and will build one of the instruments – the Fast Plasma Instrument, which will measure the ion and electron distributions and the electric and magnetic fields with unprecedentedly high millisecond time resolution and accuracy.

Currently, MMS is scheduled to launch in August 2014 from Cape Canaveral Air Force Station, FL aboard an Atlas V rocket.

Cosmic lens used to probe dark energy for first time

Astronomers have devised a new method for measuring perhaps the greatest puzzle of our universe -- dark energy. This mysterious force, discovered in 1998, is pushing our universe apart at ever-increasing speeds. For the first time, astronomers using NASA's Hubble Space Telescope were able to take advantage of a giant magnifying lens in space -- a massive cluster of galaxies -- to narrow in on the nature of dark energy. Their calculations, when combined with data from other methods, significantly increase the accuracy of dark energy measurements. This may eventually lead to an explanation of what the elusive phenomenon really is.



This image from NASA's Hubble Space Telescope shows the inner region of Abell 1689, an immense cluster of galaxies located 2.2 billion light-years away. The cluster's gravitational field is warping light from background galaxies, causing them to appear as arcs. The effect is similar to what happens when you look into a fun house mirror. Dark matter in the cluster, which represents about 80 percent of its mass, is mapped by plotting these arcs. Dark matter cannot be photographed, but its distribution is shown in the blue overlay. The dark matter distribution is then used to better understand the nature of dark energy, a pressure that is accelerating the expansion of the universe. (NASA/ESA/JPL-Caltech/Yale/CNRS)

"We have to tackle the dark energy problem from all sides," said Eric Jullo, an astronomer at NASA's Jet Propulsion Laboratory, Pasadena, Calif. "It's important to have several methods, and now we've got a new, very powerful one."

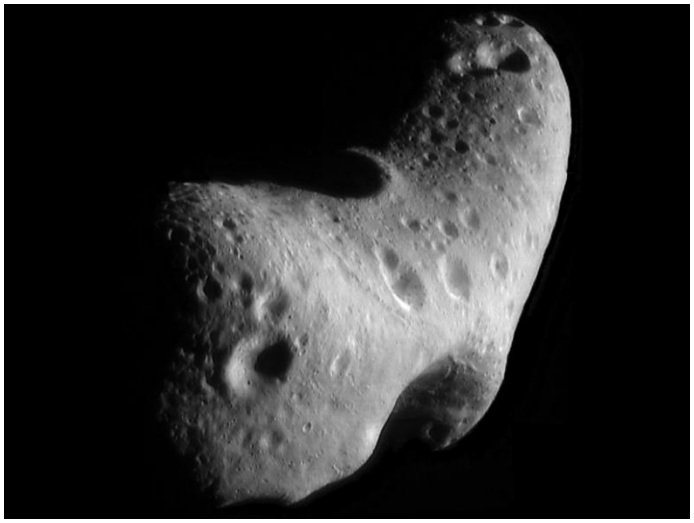
Scientists aren't clear about what dark energy is, but they do know that it makes up a large chunk of our universe -- about 72 %. Another chunk, about 24 %, is thought to be dark matter, also mysterious in nature but easier to study than dark energy because of its gravitational influence on matter that we can see. The rest of the universe, a mere four percent, is the stuff that makes up people, planets, stars and everything made up of atoms.

In their new study, the science team used images from Hubble to examine a massive cluster of galaxies, named Abell 1689, which acts as a magnifying, or gravitational, lens. The

gravity of the cluster causes galaxies behind it to be imaged multiple times into distorted shapes, sort of like a fun house mirror reflection that warps your face. Using these distorted images, the scientists were able to figure out how light from the more distant, background galaxies had been bent by the cluster -- a characteristic that depends on the nature of dark energy. Their method also depends on precise ground-based measurements of the distance and speed at which the background galaxies are traveling away from us. The team used these data to quantify the strength of the dark energy that is causing our universe to accelerate.

"What I like about our new method is that it's very visual," said Jullo. "You can literally see gravitation and dark energy bend the images of the background galaxies into arcs."

According to the scientists, their method required multiple, meticulous steps. They spent the last several years developing specialized mathematical models and precise maps of the matter -- both dark and "normal" -- constituting the Abell 1689 cluster. "We can now apply our technique to other gravitational lenses," said Priya Natarajan, a cosmologist at Yale University, New Haven, Conn. "We're exploiting a beautiful phenomenon in nature to learn more about the role that dark energy plays in our universe."



This image, taken by NASA's Near Earth Asteroid Rendezvous mission in 2000, shows a close-up view of Eros, an asteroid with an orbit that takes it somewhat close to Earth. NASA's Spitzer Space Telescope observed Eros and dozens of other near-Earth asteroids as part of an ongoing survey to study their sizes and compositions using infrared light. (NASA/JHUAPL)

Spitzer finds a flavourful mix of asteroids

New research from NASA's Spitzer Space Telescope reveals that asteroids somewhat near Earth, termed near-Earth objects, are a mixed bunch, with a surprisingly wide array of compositions. Like a piñata filled with everything from chocolates to fruity candies, these asteroids come in assorted colours and compositions. Some are dark and dull; others are shiny and bright. The Spitzer observations of 100 known near-Earth asteroids demonstrate that the objects' diversity is greater than previously thought. The findings are helping astronomers better understand near-Earth objects as a whole -- a population whose physical properties are not well known.

"These rocks are teaching us about the places they come from," said David Trilling of Northern Arizona University, Flagstaff, lead author of a new paper on the research appearing in the September 2010 issue of *Astronomical Journal*. "It's like studying pebbles in a streambed to learn about the mountains they tumbled down."

After nearly six years of operation, in May 2009, Spitzer used up the liquid coolant needed to chill its infrared detectors. It is now operating in a so-called "warm" mode (the actual temperature is still quite cold at 30 Kelvin, or minus 406 degrees Fahrenheit). Two of Spitzer's infrared channels, the shortest-wavelength detectors on the observatory, are working perfectly.

One of the mission's new "warm" programs is to survey about 700 near-Earth objects, cataloguing their individual traits. By observing in infrared, Spitzer is helping to gather more accurate estimates of asteroids' compositions and sizes than what is possible with visible light alone. Visible-light observations of an asteroid won't differentiate between an asteroid that is big and dark, or small and light. Both rocks would reflect the same amount of visible sunlight. Infrared data provide a read on the object's temperature, which then tells an astronomer more about the actual size and composition. A big, dark rock has a higher temperature than a small, light one because it absorbs more sunlight.

Trilling and his team have analyzed preliminary data on 100 near-Earth asteroids so far. They plan to observe 600 more over the next year. There are roughly 7,000 known near-Earth objects out of a population expected to number in the tens to hundreds of thousands. "Very little is known about the physical characteristics of the near-Earth population," said Trilling. "Our data will tell us more about the population, and how it changes from one object to the next. This information could be used to help plan possible future space missions to study a near-Earth object."

The data show that some of the smaller objects have surprisingly high albedos (an albedo is a measurement of how much sunlight an object reflects). Since asteroid surfaces become darker with time due to exposure to solar radiation, the presence of lighter, brighter surfaces for some asteroids may indicate that they are relatively young. This is evidence for the continuing evolution of the near-Earth object population. In addition, the fact that the asteroids observed so far have a greater degree of diversity than expected indicates that they might have different origins. Some might come from the main belt between Mars and Jupiter, and others could come from farther out in the solar system. This diversity also suggests that the materials that went into making the asteroids -- the same materials that make up our planets -- were probably mixed together like a big solar-system soup very early in its history.

The research complements that of NASA's Wide-field Infrared Survey Explorer, or WISE, an all-sky infrared survey mission also up in space now. WISE has already observed more than 430 near-Earth objects -- of these, more than 110 are newly discovered.

In the future, both Spitzer and WISE will tell us even more about the "flavours" of near-Earth objects. This could reveal new clues about how the cosmic objects might have dotted our young planet with water and organics -- ingredients needed to kick-start life.

Fermi detects 'shocking' surprise from supernova's little cousin

Astronomers using NASA's Fermi Gamma-ray Space Telescope have detected gamma-rays from a nova for the first time, a finding that stunned observers and theorists alike. The discovery overturns the notion that novae explosions lack the power to emit such high-energy radiation. A nova is a sudden, short-lived

brightening of an otherwise inconspicuous star. The outburst occurs when a white dwarf in a binary system erupts in an enormous thermonuclear explosion.

"In human terms, this was an immensely powerful eruption, equivalent to about 1,000 times the energy emitted by the sun every year," said Elizabeth Hays, a Fermi deputy project scientist at NASA's Goddard Space Flight Center in Greenbelt, Md. "But compared to other cosmic events Fermi sees, it was quite modest. We're amazed that Fermi detected it so strongly." Gamma rays are the most energetic form of light, and Fermi's Large Area Telescope (LAT) detected the nova for 15 days. Scientists believe the emission arose as a million-mile-per-hour shock wave raced from the site of the explosion.

The story opened in Japan during the predawn hours of 11 March, when amateur astronomers Koichi Nishiyama and Fujio Kabashima in Miyaki-cho, Saga Prefecture, imaged a dramatic change in the brightness of a star in the constellation Cygnus. They realized that the star, known as V407 Cyg, was 10 times brighter than in an image they had taken three days earlier. The team relayed the nova discovery to Hiroyuki Maehara at Kyoto University, who notified astronomers around the world for follow-up observations. Before this notice became widely available, the outburst was independently reported by three other Japanese amateurs: Tadashi Kojima, Tsumagoi-mura Agatsuma-gun, Gunma prefecture; Kazuo Sakaniwa, Higashichikuma-gun, Nagano prefecture; and Akihiko Tago, Tsuyama-shi, Okayama prefecture.

On 13 March, Goddard's Davide Donato was on-duty as the LAT "flare advocate," a scientist who monitors the daily data downloads for sources of potential interest, when he noticed a significant detection in Cygnus. But linking this source to the nova would take several days, in part because key members of the Fermi team were in Paris for a meeting of the LAT scientific collaboration. "This region is close to the galactic plane, which packs together many types of gamma-ray sources -- pulsars, supernova remnants, and others in our own galaxy, plus active galaxies beyond them," Donato said. "If the nova had occurred elsewhere in the sky, figuring out the connection would have been easier."

The LAT team began a concerted effort to identify the mystery source over the following days. On 17 March, the researchers decided to obtain a "target-of-opportunity" observation using NASA's Swift satellite -- only to find that Swift was already observing the same spot. "At that point, I knew Swift was targeting V407 Cyg, but I didn't know why," said Teddy Cheung, an astrophysicist at the Naval Research Laboratory (NRL) in Washington, D.C., and the lead author of the study. Examining the Swift data, Cheung saw no additional X-ray sources that could account for what Fermi's LAT was seeing. V407 Cyg had to be it.

Half an hour later, Cheung learned from other members of the LAT team that the system had undergone a nova outburst, which was the reason the Swift observations had been triggered. "When we looked closer, we found that the LAT had detected the first gamma rays at about the same time as the nova's discovery," he said.

V407 Cyg lies 9,000 light-years away. The system is a so-called symbiotic binary containing a compact white dwarf and a red giant star about 500 times the size of the Sun. "The red giant is so swollen that its outermost atmosphere is just leaking away into space," said Adam Hill at Joseph Fourier University in Grenoble, France. The phenomenon is similar to the solar wind produced by the sun, but the flow is much stronger. "Each decade, the red giant sheds enough hydrogen gas to equal the mass of Earth," he added.

The white dwarf intercepts and captures some of this gas, which accumulates on its surface. As the gas piles on for decades to centuries, it eventually becomes hot and dense enough to fuse into helium. This energy-producing process triggers a runaway reaction that explodes the accumulated gas. The white dwarf itself, however, remains intact.

The blast created a hot, dense expanding shell called a shock front, composed of high-speed particles, ionized gas and magnetic fields. According to an early spectrum obtained by Christian Buil at Castanet Tolosan Observatory, France, the nova's shock wave expanded at 11.2 million kilometres per hour -- or nearly 1 % the speed of light. The magnetic fields trapped particles within the shell and whipped them up to tremendous energies. Before they could escape, the particles had reached velocities near the speed of light. Scientists say that the gamma rays likely resulted when these accelerated particles smashed into the red giant's wind. "We know that the remnants of much more powerful supernova explosions can trap and accelerate particles like this, but no one suspected that the magnetic fields in novae were strong enough to do it as well," said NRL's Soebur Razzaque.

Supernovae remnants endure for 100,000 years and affect regions of space thousands of light-years across. Kent Wood at NRL compares astronomical studies of supernova remnants to looking at static images in a photo album. "It takes thousands of years for supernova remnants to evolve, but with this nova we've watched the same kinds of changes over just a few days," he said. "We've gone from a photo album to a time-lapse movie."

New Space Station crew announced

NASA and its international partners have assigned three new International Space Station crew members. They are targeted to launch to the station in November 2012 aboard the Russian Soyuz 33 spacecraft.

NASA astronaut Tom Marshburn, Canadian Space Agency astronaut Chris Hadfield and Russian cosmonaut Roman Romanenko will serve as flight engineers for the Expedition 34 mission. NASA astronaut Kevin Ford and Russian cosmonauts Oleg Novitskiy and Evgeny Tarelkin were previously announced as the other crew members for Expedition 34, which begins when Soyuz 31 undocks from the station in October 2012.

Expedition 35 will begin with the undocking of Soyuz 32 in March 2013. At that time, Hadfield will serve as station commander, with Marshburn and Romanenko continuing as flight engineers. Three additional crew members for Expedition 35 have yet to be assigned. They will travel to the station aboard Soyuz 34 in March 2013.

Astronauts Linda Godwin and Scott Altman leave NASA

Astronauts Linda Godwin and Scott Altman have announced plans to leave the agency. Godwin will retire and Altman will take a job in the private sector.

Godwin joined NASA in 1980 and worked in the Payload Operations Division. She was selected as an astronaut candidate in 1985. A veteran of four spaceflights, Godwin logged more than 38 days in space, including more than 10 hours during two spacewalks. She flew aboard STS-37 in 1991; served as payload commander of STS-59 in 1994; and flew on STS-76 in 1996 and STS-108 in 2001. Godwin also supported numerous technical assignments within NASA's Astronaut Office and most recently served as the assistant to the director for exploration, Flight Crew Operations Directorate.

Altman, a retired U.S. Navy captain, joined NASA in March 1995. He also has flown four shuttle missions, logging more than 51 days in space. He was the pilot of STS-90 in 1998 and STS-106 in 2000, and was commander of the final two missions to the Hubble Space Telescope, STS-109 in 2002 and STS-125 in 2009. Altman also performed other technical duties within the agency, including temporary duty to NASA Headquarters as deputy director of the Requirements Division of the Exploration Systems Mission Directorate. Most recently, he served as chief of the Exploration Branch of the Astronaut Office.

With the imminent retirement of the Space Shuttle and flight opportunities for the foreseeable future limited to a few space station crew slots per year, many of the current astronaut corps will likely move on in the near future.

NASA, ATK successfully test 5-segment solid rocket motor

With a loud roar and mighty column of flame, on 31 August 2010 NASA and ATK Aerospace Systems successfully completed a two-minute, full-scale test of the largest and most powerful solid rocket motor designed for flight. The motor is potentially transferable to future heavy-lift launch vehicle designs. The stationary firing of the first-stage development solid rocket motor, dubbed DM-2, was the most heavily instrumented solid rocket motor test in NASA history. More than 760 instruments measured 53 test objectives.

Prior to the static test, the solid rocket motor was cooled to 40 degrees Fahrenheit to verify the performance of new materials and assess motor performance at low temperatures during the full-duration test. Initial test data showed the motor performance met all expectations. "For every few degrees the temperature rises, solid propellant burns slightly faster and only through robust ground testing can we understand how material and motor performance is impacted by different operating conditions," said Alex Priskos, first stage manager for Ares Projects at NASA's Marshall Space Flight Center in Huntsville, Ala. "Ground-testing at temperature extremes pushes this system to its limits, which advances our understanding of five-segment solid rocket motor performance."

The first-stage solid rocket motor is designed to generate up to 1.6 million kilograms of thrust at launch. Information collected from this test, together with data from the first development motor test last year, will be evaluated to better understand the performance and reliability of the design.

Although similar to the solid rocket boosters that help power the space shuttle to orbit, the five-segment development motor includes several upgrades and technology improvements implemented by NASA and ATK engineers. Motor upgrades from a shuttle booster include the addition of a fifth segment, a larger nozzle throat, and upgraded insulation and liner. The motor cases are flight-proven hardware used on shuttle launches for more than three decades. The cases used in this ground test have collectively launched 59 previous missions, the earliest being STS-3.

After more testing, the first-stage solid rocket motor will be certified to fly at temperature ranges between 40-90 degrees Fahrenheit. The solid rocket motor was built as an element of NASA's Constellation Program and is managed by the Ares Projects Office at Marshall. ATK Aerospace Systems, a division of Alliant Techsystems of Brigham City, Utah, is the prime contractor.

Water deep in Earth key to survival of oldest continents

Why do we still find rocks from the Archean, one of the earliest geological eons on Earth dating from about 3.8 to 2.5 billion years ago? This is an apt question as our planet is one of the most dynamic in the solar system. Earth's crust has been constantly destroyed and created throughout its 4.5-billion-year history.

Tectonic plates are generated at mid-oceanic ridges and sink at their edges in subduction zones or mountain collisions. Continents assemble and break up in 100-hundred-million-year cycles. Yet the ancient cores of continents, called cratons, have survived this violent past. Their old rocks provide a window into the earliest days of Earth's geological history.

Cratons resemble icebergs floating in an ocean. Their deep mantle roots, to a depth of 200 kilometres or more, are largely unaffected by the asthenosphere into which they project. The asthenosphere, a zone of Earth's mantle that lies beneath the tectonic plates and consists of several hundred kilometers of deformable rock, flows like putty and drives plate tectonics. Why these roots are not destroyed by the tectonic plate engine is a puzzle.

In the 2 September issue of the journal *Nature*, Anne Peslier, a Jacobs Technology scientist working at NASA's Johnson Space Center in Houston, and her colleagues, Alan Woodland and Marina Lazarov from the University of Frankfurt, and David Bell from Arizona State University, published key results on rocks from the deepest part of a cratonic root that offer an answer to this conundrum.

These researchers analyzed water in samples found in diamond mines of southern Africa, where the Kaapvaal craton was pierced during the Cretaceous era (when dinosaurs roamed) by explosive magmas called kimberlites. These magmas soared through the mantle and crust via deep fractures, bringing with them pieces of the rocks traversed, including diamonds. The mantle rocks analyzed by Peslier and colleagues were transported from as deep as 200 km below the surface, where they had been since their formation around 3 billion years ago. These rocks are among the deepest and oldest that can be found on Earth.

It has long been suspected that the composition and temperature of the cratons played a crucial role in their survival throughout geological times. A lot of magma was extracted from the cratonic mantle early in Earth's history, which removed much of its iron, aluminum and calcium. These depletions make the cratonic roots less dense and enable them to float on the asthenosphere. "Cratons are also relatively cold compared to the asthenosphere," said Lazarov. This provides a stiffness that contributes to their resistance and makes them less likely to be destroyed in the plate tectonic cycles.

Still, with only temperature and buoyancy contributing to their stability, scientists have had a hard time explaining why cratons have survived for so long surrounded by the hot and dynamic asthenosphere. "The water content of the main mineral of the mantle, olivine, is the key to cratonic root survival," said Peslier.

Water is present in the crystal structure of minerals from Earth's mantle and it acts to soften the most abundant one, olivine. Peslier and colleagues found that at the very base of the cratons, at the boundary with the asthenosphere, olivines contain hardly any water. That makes these olivines very hard to deform or break up and helps explain why cratonic roots do not get removed by the asthenosphere: their dry olivines make them strong and resistant.

Why the bottom of the cratonic mantle has dry olivines remains a matter of speculation. “The peculiar chemical and physical conditions at these high pressures may render the fluids present at these depths rich in methane instead of water,” said Woodland. Bell suggests that melts generated in the asthenosphere may pick up water while passing through the base of the cratonic root and bring it to the overlying shallow mantle. Knowing how much water is present deep in terrestrial planets and moons, like Mars or Earth or its moon, is crucial to understanding their history, dynamics and volcanism.

Recipe for water: just add starlight

ESA’s Herschel infrared space observatory has discovered that ultraviolet starlight is the key ingredient for making water in space. It is the only explanation for why a dying star is surrounded by a gigantic cloud of hot water vapour.

Every recipe needs a secret ingredient. When astronomers discovered an unexpected cloud of water vapour around the old star IRC+10216 in 2001, they immediately began searching for the source. Stars like IRC+10216 are known as carbon stars and are thought not to make much water. Initially they suspected the star’s heat must be evaporating comets or even dwarf planets to produce the water. Now, Herschel’s PACS and SPIRE instruments have revealed that the secret ingredient is ultraviolet light, because the water is too hot to have come from the destruction of icy celestial bodies.

“This is a good example of how better instruments can change our picture completely,” says Leen Decin, Katholieke Universiteit Leuven, Belgium, the lead author of a paper about this work. The superb sensitivity of Herschel’s instruments has revealed that the water around IRC+10216 varies in temperature from about –200°C to 800°C, which indicates that it is being formed much closer to the star than comets can stably exist.

IRC+10216 is a red giant star, hundreds of times the Sun’s size, although only a few times its mass. If it replaced the Sun in our Solar System, it would extend beyond the orbit of Mars. It is 500 light years away and while it is barely detectable at visible wavelengths, even in the largest telescopes, it is the brightest star in the sky at some infrared wavelengths. This is because it is surrounded by a huge envelope of dust that absorbs almost all its visible radiation and re-emits it as infrared light. It is in the envelope that the water vapour has been found. But how did the water get there?

The vital clue was found by Herschel. Observations had already revealed the clumpy structure in the dusty envelope around IRC+10216. The Herschel water detection made the astronomers realise that ultraviolet light from surrounding stars can reach deep into the envelope between the clumps and break up molecules such as carbon monoxide and silicon monoxide, releasing oxygen atoms. The oxygen atoms then attach themselves to hydrogen molecules, forming water. “This is the only mechanism that explains the full range of the water’s temperature,” says Decin. The closer to the star the water is formed, the hotter it will be. Decin and her colleagues now plan to extend the observations to other carbon stars. “We are very hopeful that Herschel will find the same situations around those stars too,” she says.

On Earth, carbon compounds and water are the key ingredients for life. Now, thanks to Herschel, we know that both can be made around IRC+10216, and that the secret ingredient for water is ultraviolet light from surrounding stars.

Kepler mission discovers two planets transiting same star

NASA's Kepler spacecraft has discovered the first confirmed planetary system with more than one planet crossing in front of, or transiting, the same star. The transit signatures of two distinct planets were seen in the data for the sun-like star designated Kepler-9. The planets were named Kepler-9b and 9c. The discovery incorporates seven months of observations of more than 156,000 stars as part of an ongoing search for Earth-sized planets outside our solar system.

Kepler's ultra-precise camera measures tiny decreases in stars' brightness that occur when a planet transits them. The size of the planet can be derived from these temporary dips. The distance of the planet from a star can be calculated by measuring the time between successive dips as the planet orbits the star. Small variations in the regularity of these dips can be used to determine the masses of planets and detect other non-transiting planets in the system.

In June 2010, Kepler mission scientists submitted findings for peer review that identified more than 700 planet candidates in the first 43 days of Kepler data. The data included five additional candidate systems that appear to exhibit more than one transiting planet. The Kepler team recently identified a sixth target exhibiting multiple transits and accumulated enough followup data to confirm this multi-planet system. "Kepler's high-quality data and round-the-clock coverage of transiting objects enable a whole host of unique measurements to be made of the parent stars and their planetary systems," said Doug Hudgins, the Kepler program scientist at NASA Headquarters in Washington.

Scientists refined the estimates of the masses of the planets using observations from the W.M. Keck Observatory in Hawaii. The observations show Kepler-9b is the larger of the two planets, and both have masses similar to but less than Saturn. Kepler-9b lies closest to the star, with an orbit of about 19 days, while Kepler-9c has an orbit of about 38 days. By observing several transits by each planet over the seven months of data, the time between successive transits could be analyzed.

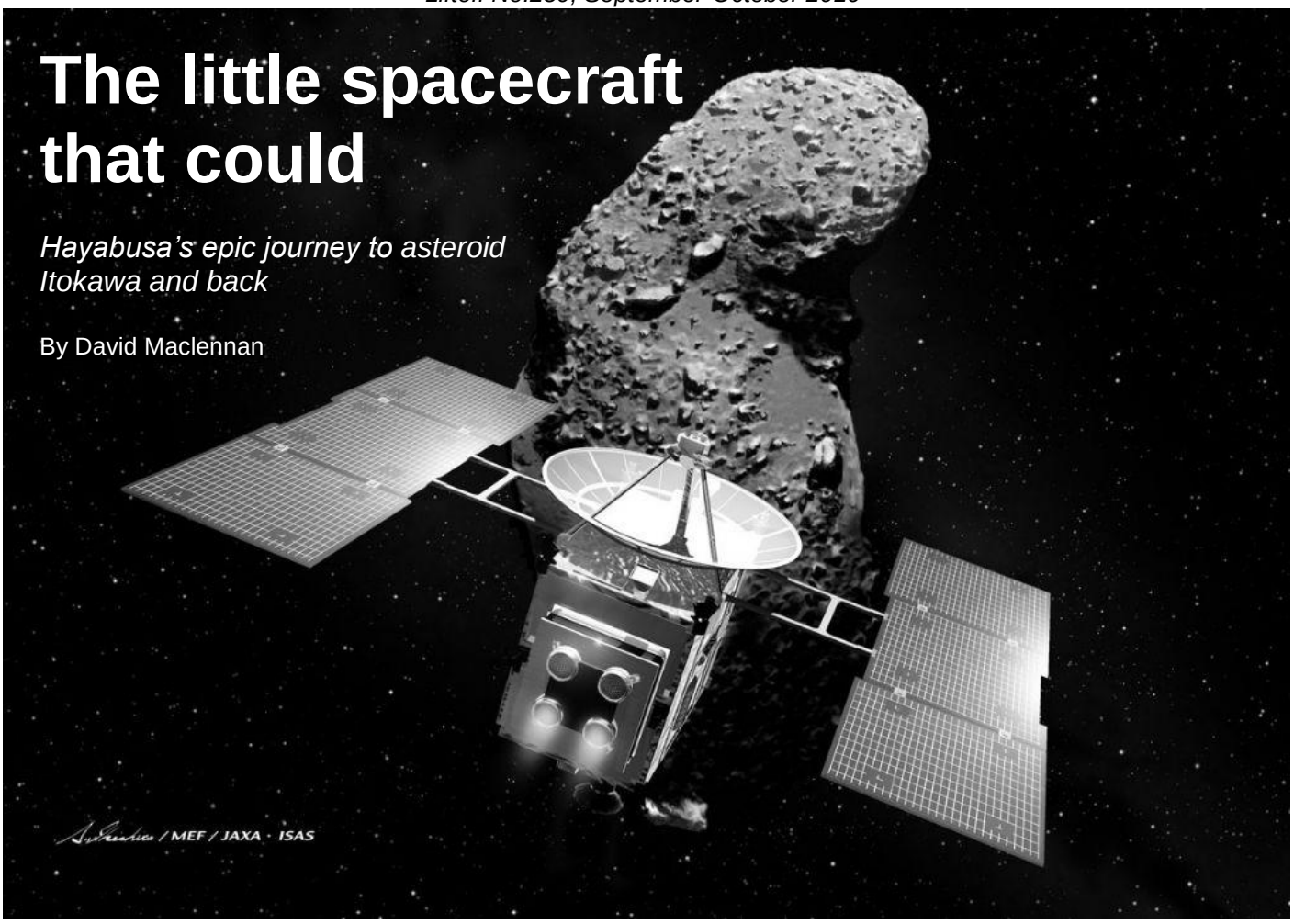
"This discovery is the first clear detection of significant changes in the intervals from one planetary transit to the next, what we call transit timing variations," said Matthew Holman, a Kepler mission scientist from the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. "This is evidence of the gravitational interaction between the two planets as seen by the Kepler spacecraft."

In addition to the two confirmed giant planets, Kepler scientists also have identified what appears to be a third, much smaller transit signature in the observations of Kepler-9. That signature is consistent with the transits of a super-Earth-sized planet about 1.5 times the radius of Earth in a scorching, near-sun 1.6 day-orbit. Additional observations are required to determine whether this signal is indeed a planet or an astronomical phenomenon that mimics the appearance of a transit.

The little spacecraft that could

Hayabusa's epic journey to asteroid Itokawa and back

By David Maclennan



Artist's impression of Hayabusa approaching asteroid Itokawa in 2005 (JAXA)

On the night of 13 June 2010, in the skies over southern Australia, Japan's ill-starred asteroid sampling mission, Hayabusa, returned home seven years after leaving Earth. Before burning up in the atmosphere, Hayabusa released a small re-entry capsule that scientists hoped would contain at least a few grains of material from the mission's target, an asteroid named Itokawa.

That Hayabusa made it back at all was something of a miracle, and a testament to the team of engineers from the Japan Aerospace Exploration Agency (JAXA) who, in an Apollo 13-like display of determination, nursed the ailing spacecraft back to Earth following multiple system failures, including most of its propulsion system.

Hayabusa was launched on 9 May 2003 aboard an MV-5 rocket from the Uchinoura Launch Centre, on the island of Kyushu in Japan. Originally knows as MUSES-C, the spacecraft was renamed Hayabusa (meaning 'peregrine falcon') following launch, as is customary for Japanese spacecraft.

Hayabusa was targeted to an asteroid named 25143 Itokawa, in honour of Hideo Itokawa (1912-1999), who was one of the pioneers of Japan's space programme. Discovered in 1998, asteroid Itokawa was chosen as Hayabusa's target because it was within the capability of the spacecraft to reach it, rather than for any intrinsic scientific reasons. Measuring only 535 x 294 x 209 metres, Itokawa is the smallest asteroid ever visited by a spacecraft.

Hayabusa weighed 510 kilograms, with the main spacecraft body measuring 1 x 1.6 x 2 metres. Power was supplied by two solar panels, spanning 5.7 metres after deployment. Hayabusa's propulsion came from four ion thrusters, though only two were required to operate the mission. The spacecraft carried five science instruments, including two cameras. In addition, Hayabusa carried a sample return capsule and a mini-lander named MINERVA.

First troubles

Hayabusa's troubles began early when a major solar flare damaged Hayabusa's solar cells, reducing their efficiency, which in turn reduced the thrust levels from the ion thrusters, which would delay the craft's arrival at Itokawa. Also, one of the four ion thrusters malfunctioned and was taken off-line, but as noted above only two were required to perform the mission.

Hayabusa swung by Earth in May 2004 on a gravity-assist flyby, becoming the first spacecraft to perform this manoevre using ion thrusters. Then in July 2005 one of its three reaction wheels failed (reaction wheels are a type of flywheel used to stabilise a spacecraft's attitude). The spacecraft was, however, able to maintain three-axis control using the remaining two reaction wheels.

Approaching Itokawa

By now Hayabusa was nearing its target. The first images of Itokawa were taken on 5 September 2004, but it would be a year later before the spacecraft's cameras were able to resolve the asteroid's elongated kumara-like shape. The official encounter began in September 2005 when Hayabusa reached a position about 20 kilometres from the asteroid. Engineers called this the "gate position", and Hayabusa spent about a fortnight at

The launch of Hayabusa atop an MV-5 rocket from the Uchinoura Launch Centre on 9 May 2003 (JAXA)

this point making multispectral studies and movies showing the asteroid's rotation. The Sun was directly behind Hayabusa, and its silhouette could be seen on Itokawa's surface.

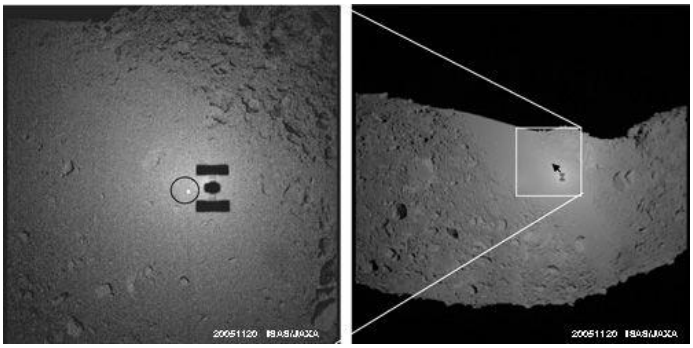
Hayabusa then edged closer to Itokawa, taking up a new position (called "home position") some 7 kilometres from the asteroid. However, as it was doing so a second reaction wheel failed in October 2005, forcing controllers to use the craft's chemical thrusters to help maintain attitude as the single remaining reaction when could not do this by itself. Despite this setback, observations of Itokawa continued, with the spacecraft taking side-on views and imaging both poles.

Touchdown

With the surveys complete, Hayabusa prepared for the climax of the mission – the retrieval of samples from Itokawa's surface. The spacecraft first moved in closer, coming to within 3 kilometres of the asteroid. On 12 November Hayabusa released the 0.6-kilogramme MINERVA (Micro/Nano Experimental Robot Vehicle for Asteroid), a mini space hopper. Unfortunately, the targeting was off and Minerva missed the asteroid entirely. Then on 20 November 2005 Hayabusa released a small reflective ball-shaped object towards Itokawa's surface called a target marker, the purpose of which was to aid the main spacecraft in ranging to the surface. The target marker also contained 880,000 names collected by JAXA and the US-based Planetary Society (including this writer's!).

Hayabusa then made its first attempt at touching down on Itokawa's surface. There was some confusion about what happened next. Early reports stated that Hayabusa had hovered about 10 metres above the surface for half an hour but did not land. Later reports confirmed that the spacecraft had indeed touched the surface. A one-metre-long sampler horn extended from the bottom of the spacecraft, and when this touched the surface two small pellets were to be fired at the surface to stir up material to be collected via the horn.

However, Hayabusa was not supposed to have spent so long close to the heated surface of the asteroid. As the spacecraft heated up its on-board systems switched to a spin-stabilised safe mode, commanding the spacecraft to move away from Itokawa to a distance of 100 kilometres.



Hayabusa casts a shadow as it approaches asteroid Itokawa. Note the target marker deployed onto the surface as a reference point for attitude determination of the spacecraft during its descent (circled at left) (JAXA)

More troubles

It was not clear if the pellets had fired or not, so a second landing attempt was made on 26 November. But new troubles now arose. Following the second landing attempt, Hayabusa ascended away from Itokawa using its chemical thrusters. However, a fuel leak combined with the loss of three-axis stabilization sent the spacecraft out of control, and contact with Earth was lost.

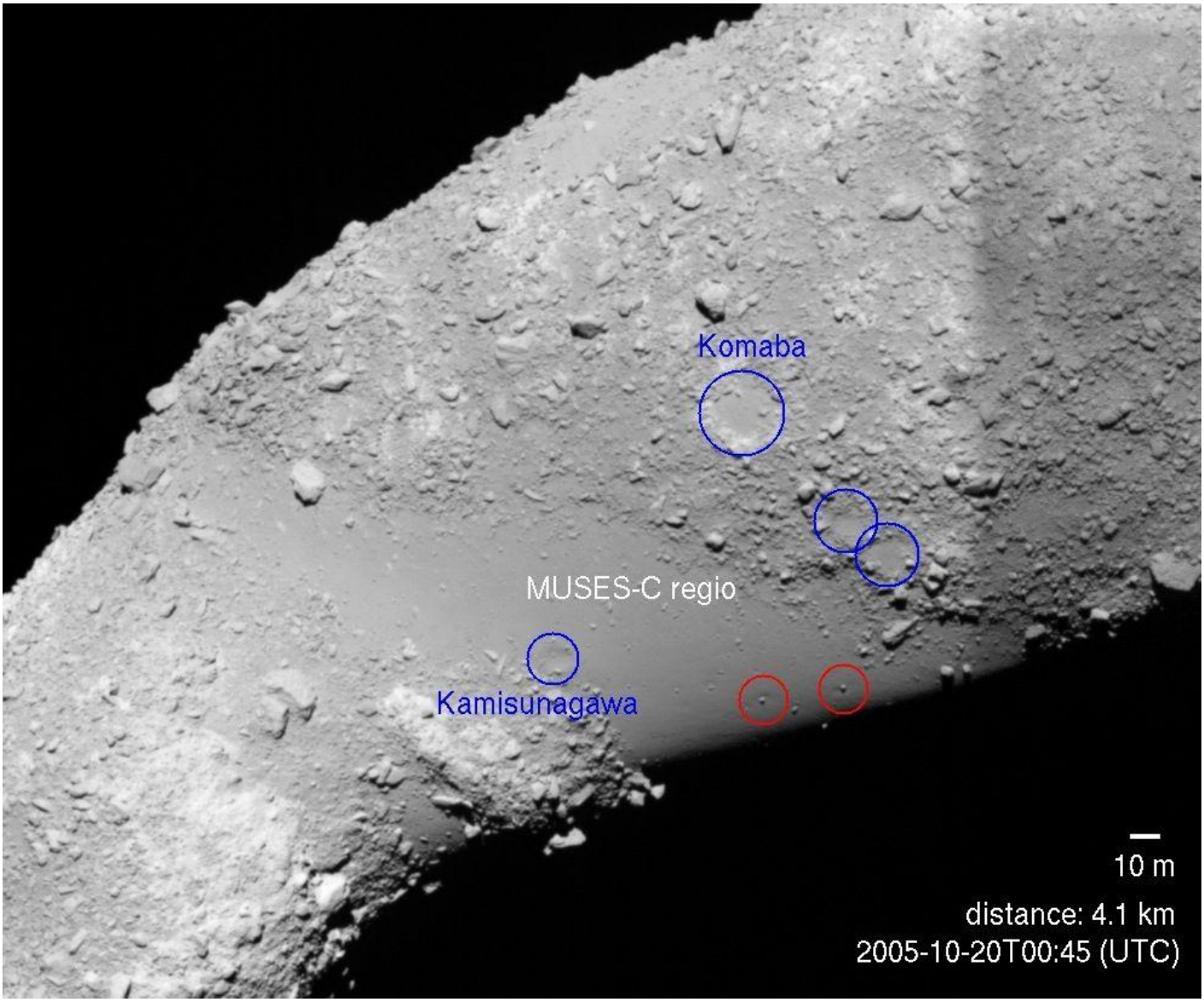
The situation remained confused for several weeks. Both of the thruster systems weren't working, three-axis stabilization could not be resumed, and it became apparent that the sample collection system may not have worked properly. Additionally, Hayabusa was to have departed from the vicinity of Itokawa in December 2005 in order to return to Earth in mid-2007. However, the difficulties in regaining control and communications meant that this departure window would be missed, delaying Hayabusa's return to Earth until 2010.

Full contact was finally resumed in March 2006, but the little spacecraft was far from healthy. Its chemical thruster system had totally failed, as had several on-board battery cells. By early 2007, the mission's engineers had devised a strategy for getting Hayabusa back to Earth. First, they slowly recharged the damaged battery, eventually getting enough power in to close up the sample return capsule. The engineers had also devised a way of regaining three-axis stabilisation using a combination of the one remaining reaction wheel and venting puffs of xenon gas from the thrusters.

More woes on the journey home

In April 2007, Hayabusa began its long journey home, using the single remaining working thruster (thruster D). By August, engineers had restored thrusters B and C to intermittent working order, and by October the spacecraft was once again spin-stabilised and quietly cruising homeward.

On 4 February 2009 the next phase of the troubled journey began, as engineers regained three-axis stabilization using a combination of the one working reaction wheel, the gimbaled ion engines, and solar pressure on Hayabusa's solar panels – in

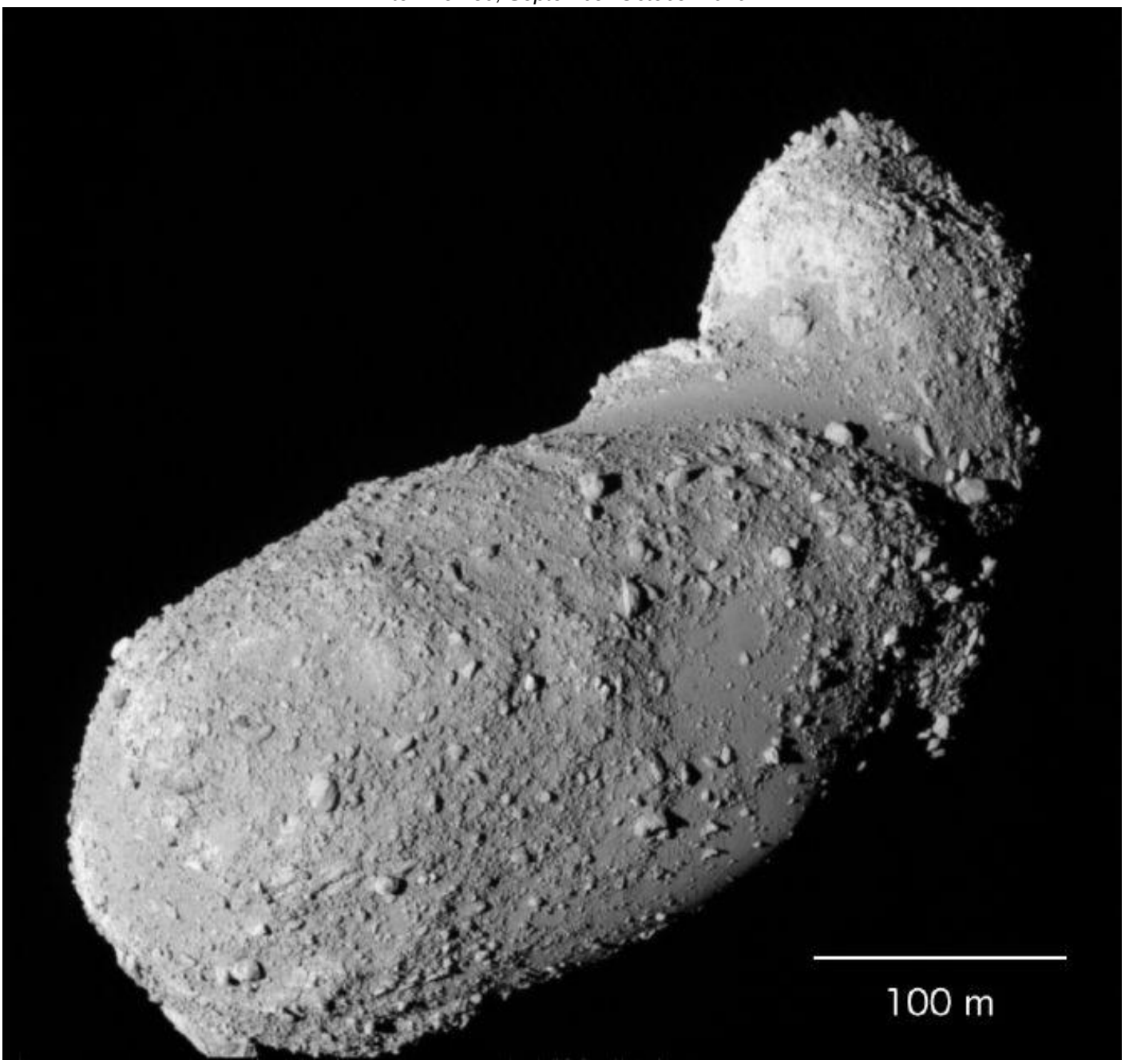


(Above) An image of Itokawa taken on 20 November 2005, showing the names given to some features, including an unusually smooth region in the centre (JAXA)

(Below) Hayabusa's re-entry capsule lies where it landed in South Australia on 13 June 2010 (JAXA)

(Above) JAXA engineers are all smiles following the successful landing and retrieval of Hayabusa's re-entry capsule (JAXA)

(Below) A few grains of material are visible inside the re-entry capsule after it was opened in Japan. It is not yet known if the grains are from Itokawa or not (JAXA)



An image of asteroid Itokawa taken by Hayabusa on 23 October 2005 (JAXA)

effect, partial solar-sailing. But then in November, thruster D – the one fully-working thruster – finally failed, having far exceeded its design life. That left only thruster C working, enough for the cruise phase but not enough for the final course correction to get it back to Earth.

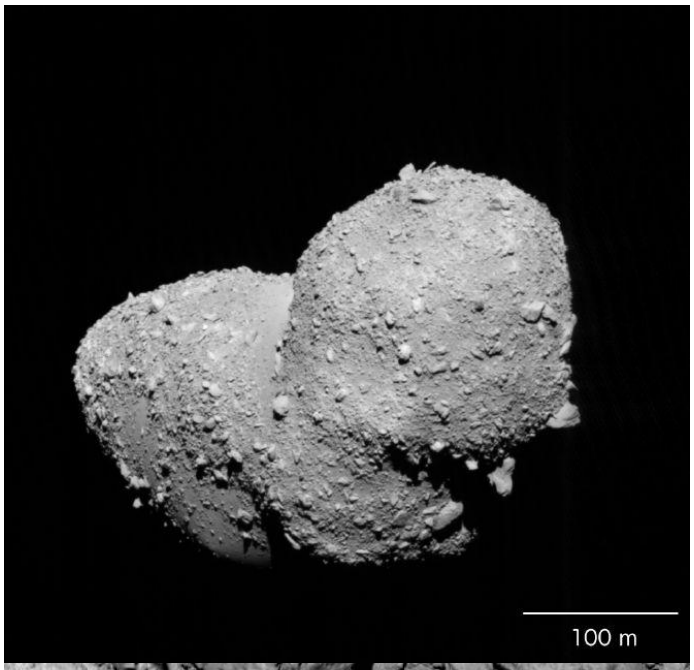
However, having got this far, the JAXA engineers weren't about to give up on their little spacecraft, and like all good rocket scientists, they already had a plan up their sleeves. Each of the craft's ion engines comprised two main components: an ion beam and a neutraliser. By using the neutraliser from thruster A, which hadn't been used on the mission because its ion beam had failed, they were able to neutralise thruster B's ion beam, thereby providing the second ion thruster needed to get home.

Home at last

Hayabusa was now closing in on Earth. In April of this year powered flight was completed and engineers began to prepare for the capsule's return to the Woomera Prohibited Area in South Australia. Five trajectory corrections tweaked the craft's path, and three hours before it hit the atmosphere, Hayabusa released its 40-centimetre-wide re-entry capsule, spinning it up to ensure it remained stabilised during its 40,000 km/hr entry into the atmosphere. A special heat shield protected the capsule from the 2,700-deg. Celsius heat of re-entry.

Meanwhile, Hayabusa itself burned up in the atmosphere in a brilliant fireball – no doubt a bittersweet moment for the JAXA mission engineers, just as the destruction of Apollo 13's lunar module Aquarius was for the NASA team in April 1970. But Hayabusa's precious cargo, the re-entry capsule, made a successful parachute descent to the desert below, and hours later was on its way back to Japan for study at JAXA's Sagamihara campus.

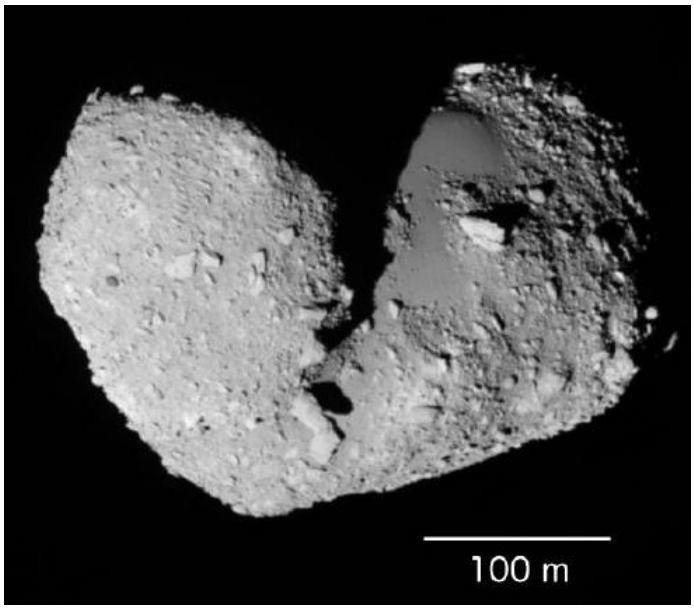
After cleaning, the capsule was opened in a special clean room – and there were indeed a few grains of material inside!



(*Top) A view of one end of Itokawa, taken on 23 October 2005. The grey rock at top centre is called Black Boulder (JAXA)*

(Bottom) A closeup of Itokawa's rubble-strewn surface (JAXA)

However, so far it is unclear whether the grains are from asteroid Itokawa itself, or are interplanetary dust grains picked up while the container was still open in space, or are even from Earth. Careful study will be made of the grains before a determination is made. It is to be hoped that they are indeed particles from Itokawa, for it would be a fitting reward for the JAXA engineers who worked so hard against seemingly



A view of Itokawa taken on 18 October 2005. The rock sticking out at lower centre is called Pencil Boulder. Its shadow can also be seen clearly (JAXA)

impossible odds to get Hayabusa back to Earth. It was without doubt one of the great against-all-odds success stories in the annals of solar system exploration.

A follow-on mission to Hayabusa is already in the works. The spacecraft itself will be similar to Hayabusa, in order to keep costs down, but hopefully it will enjoy smoother sailing than its predecessor.

Instruments on NASA's Phoenix Mars Lander included the Thermal and Evolved Gas Analyzer, right, which analyzed the atmosphere, as well as soil samples. (NASA)

Missing piece inspires new look at Mars puzzle

Experiments prompted by a 2008 surprise from NASA's Phoenix Mars Lander suggest that soil examined by NASA's Viking Mars landers in 1976 may have contained carbon-based chemical building blocks of life. "This doesn't say anything about the question of whether or not life has existed on Mars, but it could make a big difference in how we look for evidence to answer that question," said Chris McKay of NASA's Ames Research Center, Moffett Field, Calif. McKay coauthored a study published online by the *Journal of Geophysical Research - Planets*, reanalyzing results of Viking's tests for organic chemicals in Martian soil.

The only organic chemicals identified when the Viking landers heated samples of Martian soil were chloromethane and dichloromethane -- chlorine compounds interpreted at the time as likely contaminants from cleaning fluids. But, those chemicals are exactly what the new study found when a little perchlorate -- the surprise finding from Phoenix -- was added to desert soil from Chile containing organics and analyzed in the manner of the Viking tests.

"Our results suggest that not only organics, but also perchlorate, may have been present in the soil at both Viking landing sites," said the study's lead author, Rafael Navarro-González of the National Autonomous University of Mexico, Mexico City.

Organics can come from non-biological or biological sources. Many meteorites raining onto Mars and Earth for the past 5 billion years contain organics. Even if Mars has never had life, scientists before Viking anticipated that Martian soil would contain organics from meteorites. "The lack of organics was a big surprise from the Vikings," McKay said. "But for 30 years we were looking at a jigsaw puzzle with a piece missing. Phoenix has provided the missing piece: perchlorate. The perchlorate discovery by Phoenix was one of the most important results from Mars since Viking."

Perchlorate, an ion of chlorine and oxygen, becomes a strong oxidant when heated. "It could sit there in the Martian soil with organics around it for billions of years and not break them down, but when you heat the soil to check for organics, the perchlorate destroys them rapidly," McKay said.

This interpretation proposed by Navarro-González and his four co-authors challenges the interpretation of Viking scientists that Martian organic compounds were not present in their samples at the detection limit of the Viking experiment. Instead the Viking scientists interpreted the chlorine compounds as contaminants. Upcoming missions to Mars and further work on meteorites from Mars are expected to help resolve this question.

The Curiosity rover that NASA's Mars Science Laboratory mission will deliver to Mars in 2012 will carry the Sample Analysis at Mars (SAM) instrument provided by NASA Goddard Space Flight Center, Greenbelt, Md. In contrast to Viking and Phoenix, Curiosity has the capability to rove and can thus chemically analyze a wider variety of rocks and samples. SAM can check for organics in Martian soil and powdered rocks by baking samples to even higher temperatures than Viking did and also by using an alternative liquid-extraction method at much lower heat. Combining these methods on a range of samples

may enable further testing of the new report's hypothesis that oxidation by heated perchlorates that might have been present in the Viking samples was destroying organics.

One reason the chlorinated organics found by Viking were interpreted as contaminants from Earth was that the ratio of two isotopes of chlorine in them matched the three-to-one ratio for those isotopes on Earth. The ratio for them on Mars has not been clearly determined yet. If it is found to be much different than Earth's, that would support the 1970s interpretation. If organic compounds can indeed persist in the surface soil of Mars, contrary to the predominant thinking for three decades, one way to search for evidence of life on Mars could be to check for types of large, complex organic molecules, such as DNA, that are indicators of biological activity. "If organics cannot persist at the surface, that approach would not be wise, but if they can, it's a different story," McKay said.

Data shed new light about water and volcanoes on Mars

Data from NASA's Phoenix Mars Lander suggest liquid water has interacted with the Martian surface throughout the planet's history and into modern times. The research also provides new evidence that volcanic activity has persisted on the Red Planet into geologically recent times, several million years ago.

Although the lander, which arrived on Mars on May 25, 2008, is no longer operating, NASA scientists continue to analyze data gathered from that mission. These recent findings are based on data about the planet's carbon dioxide, which makes up about 95 percent of the Martian atmosphere. "Atmospheric carbon dioxide is like a chemical spy," said Paul Niles, a space scientist at NASA's Johnson Space Center in Houston. "It infiltrates every part of the surface of Mars and can indicate the presence of water and its history."

Phoenix precisely measured isotopes of carbon and oxygen in the carbon dioxide of the Martian atmosphere. Isotopes are variants of the same element with different atomic weights. Niles is lead author of a paper about the findings published in the online edition of the journal *Science*. The paper explains the ratios of stable isotopes and their implications for the history of Martian water and volcanoes.

"Isotopes can be used as a chemical signature that can tell us where something came from, and what kinds of events it has experienced," Niles said. This chemical signature suggests that liquid water primarily existed at temperatures near freezing and that hydrothermal systems similar to Yellowstone's hot springs have been rare throughout the planet's past. Measurements concerning carbon dioxide showed Mars is a much more active planet than previously thought. The results imply Mars has replenished its atmospheric carbon dioxide relatively recently, and the carbon dioxide has reacted with liquid water present on the surface.

Measurements were performed by an instrument on Phoenix called the Evolved Gas Analyzer. The instrument was capable of doing more accurate analysis of carbon dioxide than similar instruments on NASA's Viking landers in the 1970s. The Viking Program provided the only previous Mars isotope data sent back to Earth.

The low gravity and lack of a magnetic field on Mars mean that as carbon dioxide accumulates in the atmosphere, it will be lost to space. This process favors loss of a lighter isotope named carbon-12 compared to carbon-13. If Martian carbon dioxide had experienced only this process of atmospheric loss without some additional process replenishing carbon-12, the ratio of carbon-13 to carbon-12 would be much higher than what Phoenix measured. This suggests the Martian atmosphere recently has been replenished with carbon dioxide emitted from volcanoes, and volcanism has been an active process in Mars' recent past. However, a volcanic signature is not present in the proportions of two other isotopes, oxygen-18 and oxygen-16, found in Martian carbon dioxide. The finding suggests the carbon dioxide has reacted with liquid water, which enriched the oxygen in carbon dioxide with the heavier oxygen-18.

Niles and his team theorize this oxygen isotopic signature indicates liquid water has been present on the Martian surface recently enough and abundantly enough to affect the composition of the current atmosphere. The findings do not reveal specific locations or dates of liquid water and volcanic vents, but recent occurrences of those conditions provide the best explanations for the isotope proportions.

Tracing the big picture of Mars' atmosphere

One of the instruments on a 2016 mission to orbit Mars will provide daily maps of global, pole-to-pole, vertical distributions of the temperature, dust, water vapour and ice clouds in the Martian atmosphere. The joint European-American mission, ExoMars Trace Gas Orbiter, will seek faint gaseous clues about possible life on Mars. This instrument, called the ExoMars Climate Sounder, will supply crucial context with its daily profiling of the atmosphere's changing structure.

The European Space Agency and NASA have selected five instruments for ExoMars Trace Gas Orbiter. The European Space Agency will provide one instrument and the spacecraft. NASA will provide four instruments, including ExoMars Climate Sounder, which is coming from the Jet Propulsion Laboratory, Pasadena, Calif. Two of the other selected instruments are spectrometers -- one each from Europe and the United States -- designed to detect very low concentrations of methane and other important trace gases in the Martian atmosphere.

"To put the trace-gas measurements into context, you need to know the background structure and circulation of the atmosphere," said JPL's Tim Schofield, principal investigator for the ExoMars Climate Sounder. "We will provide the information needed to understand the distribution of trace gases identified by the spectrometers. We'll do this by characterizing the role of atmospheric circulation and aerosols, such as dust and ice, in trace-gas transport and in chemical reactions in the atmosphere affecting trace gases."

The ExoMars Climate Sounder is an infrared radiometer designed to operate continuously, day and night, from the spacecraft's orbit about 400 kilometres above the Martian surface. It can pivot to point downward or toward the horizon, measuring temperature, water vapour, dust and ices for each 5-kilometre increment in height throughout the atmosphere from ground level to 90 kilometres altitude.

Schofield and his international team have two other main goals for the investigation, besides aiding in interpretation of trace-gas detections. One is to extend the climate mapping record currently coming from a similar instrument, the Mars Climate Sounder, on NASA's Mars Reconnaissance Orbiter, which has been working at Mars since 2006. The orbital geometry of the Mars Reconnaissance Orbiter mission enables this sounder to record atmospheric profiles only at about 3 p.m. and 3 a.m. during the Martian day, except near the poles. The ExoMars Trace Gas Orbiter will fly an orbital pattern that allows the spacecraft to collect data at all times of day, at all latitudes. "We'll fill in information about variability at different times of day, and we'll add to the number of Mars years for understanding year-to-year variability," said Schofield. "The most obvious year-

to-year change is that some years have global dust storms and others don't. We'd like to learn whether there's anything predictive for anticipating the big dust storms, and what makes them so variable from year to year."

A third research goal is to assist future landings on Mars by supplying information about the variable density of the atmosphere. At a chosen landing site, atmospheric density can change from one day to the next, affecting a spacecraft's descent. "We want to provide background climatology for what to expect at a given site, in a given season, for a particular time of day, and also nearly real-time information for the atmospheric structure in the days leading up to the landing of a spacecraft launched after 2016," said Schofield.

The 2016 ExoMars Trace Gas Orbiter is the first in a series of planned Mars mission collaborations of the European Space Agency and NASA. A variable presence of small amounts of methane in the Martian atmosphere has been indicated from orbital and Earth-based observations. A key goal of the mission is to gain a better understanding of methane and other trace gases that could be evidence about possible biological activity. Methane can be produced both biologically and without life.

Besides the two spectrometers and the climate sounder, the orbiter's selected instruments include two NASA-provided imagers: a high-resolution, stereo, color imager, and a wide-angle, color, weather camera. The orbiter will also serve as a communications relay for missions on the surface of Mars and will carry a European-built descent-and-landing demonstration module designed to operate for a few days on the Mars surface. JPL, a division of the California Institute of Technology, manages NASA's roles in the mission.

Joint mission to Mars selects instruments

NASA and the European Space Agency (ESA) have embarked on a joint program to explore Mars in the coming decades and selected the five science instruments for the first mission. The principal investigator for one of the instruments, and the management for NASA's roles in the mission, are based at NASA's Jet Propulsion Laboratory, Pasadena, Calif.

The ExoMars Trace Gas Orbiter, scheduled to launch in 2016, is the first of three joint robotic missions to the Red Planet. It will study the chemical makeup of the Martian atmosphere with a 1000-fold increase in sensitivity over previous Mars orbiters. The mission will focus on trace gases, including methane, which could be potentially geochemical or biological in origin and be indicators for the existence of life on Mars. The mission also will serve as an additional communications relay for Mars surface missions beginning in 2018.

"Independently, NASA and ESA have made amazing discoveries up to this point," said Ed Weiler, associate administrator of NASA's Science Mission Directorate in Washington. "Working together, we'll reduce duplication of effort, expand our capabilities and see results neither ever could have achieved alone."

NASA and ESA invited scientists worldwide to propose the spacecraft's instruments. The five selected were from 19 proposals submitted in January. Both agencies evaluated the submissions and chose those with the best science value and lowest risk. The selection of the instruments begins the first phase of the new NASA-ESA alliance for future ventures to Mars.

The instruments and the principal investigators are:

Mars Atmosphere Trace Molecule Occultation Spectrometer -- A spectrometer designed to detect very low concentrations of the molecular components of the Martian atmosphere. (Paul Wennberg, California Institute of Technology, Pasadena, Calif.)

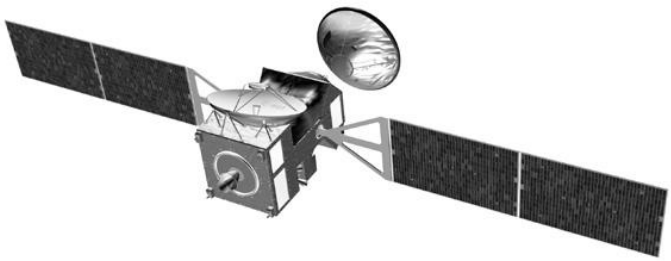
High Resolution Solar Occultation and Nadir Spectrometer -- A spectrometer designed to detect traces of the components of the Martian atmosphere and to map where they are on the surface. (Ann C. Vandaele, Belgian Institute for Space Aeronomy, Brussels, Belgium.)

ExoMars Climate Sounder -- An infrared radiometer that provides daily global data on dust, water vapor and other materials to provide the context for data analysis from the spectrometers. (John Schofield, NASA's Jet Propulsion Laboratory.)

High Resolution Color Stereo Imager -- A camera that provides four-color stereo imaging at a resolution of two million pixels over an 8.5 kilometre swath. (Alfred McEwen, University of Arizona, Tucson.)

Mars Atmospheric Global Imaging Experiment -- A wide-angle, multi-spectral camera to provide global images of Mars in support of the other instruments. (Bruce Cantor, Malin Space Science Systems, San Diego.)

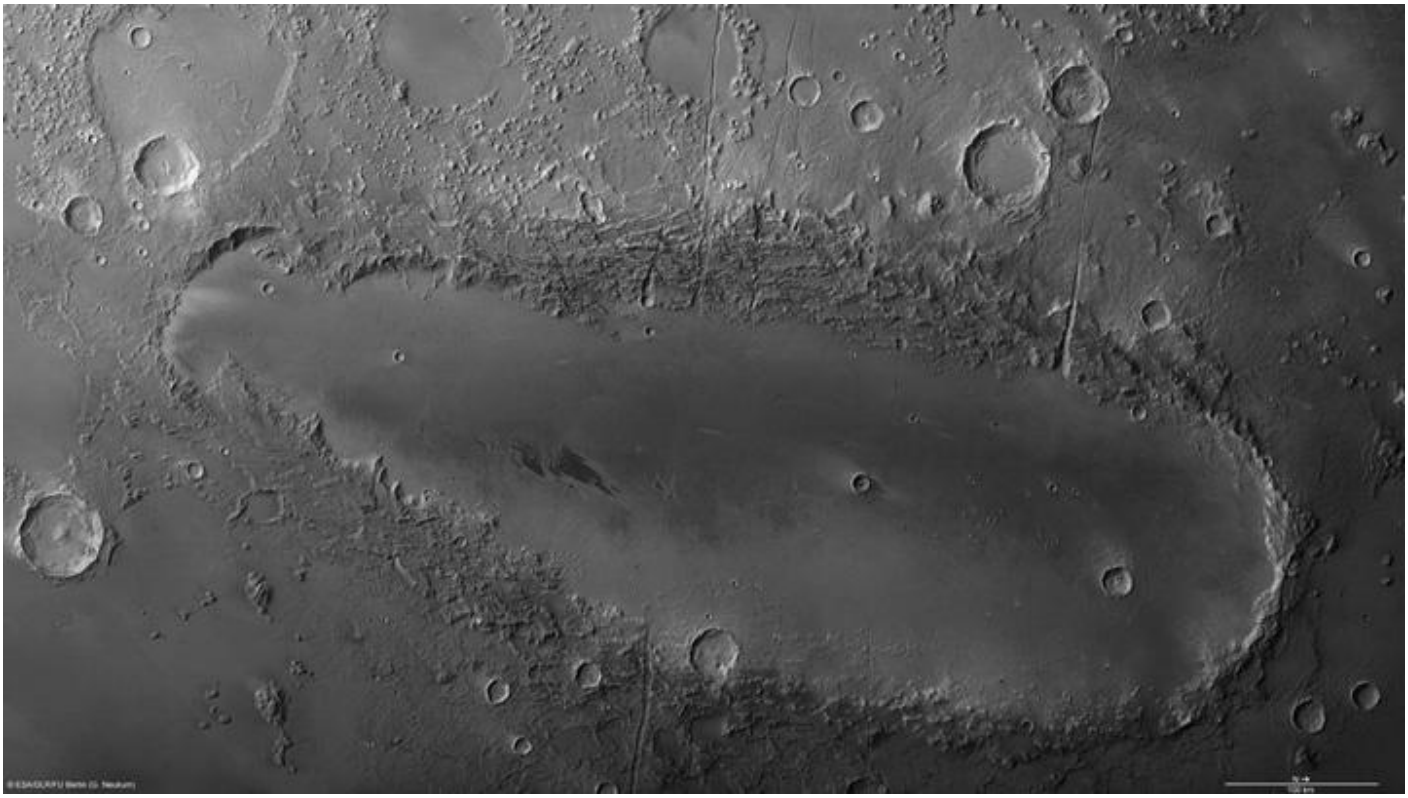
The science teams on all the instruments have broad international participation from Europe and the United States, with important hardware contributions from Canada and Switzerland. "To fully explore Mars, we want to marshal all the talents we can on Earth," said David Southwood, ESA director for Science and Robotic Exploration. "Now NASA and ESA are combining forces for the joint ExoMars Trace Gas Orbiter mission. Mapping methane allows us to investigate further that most important of questions: Is Mars a living planet, and if not, can or will it become so in the future?"



The ExoMars Trace Gas Orbiter (ESA)

NASA and ESA share a common interest in conducting robotic missions to the Red Planet for scientific purposes and to prepare for possible human visits. After a series of extensive discussions, the science heads of both agencies agreed on a plan of cooperation during a July 2009 meeting in Plymouth, England, later confirmed by ESA Director General Jean-Jacques Dordain and NASA Administrator Charles Bolden in a statement of intent that was signed in November 2009.

The plan consists of two Mars cooperative missions in 2016 and 2018, and a later joint sample return mission. The 2016 mission features the European-built ExoMars Trace Gas Orbiter, a European-built small lander demonstrator, a primarily-U.S. international science payload, and NASA-provided launch vehicle and communications components. ESA member states will provide additional instrument support. The 2018 mission consists of a European rover with a drilling capability, a NASA rover capable of caching selected samples for potential future



Orcus Patera is an enigmatic elliptical depression located between the volcanoes of Elysium Mons and Olympus Mons. This well-defined depression extends approximately 380 km by 140 km in a NNE–SSW direction. It has a rim that rises up to 1800 m above the surrounding plains, while the floor of the depression lies 400–600 m below the surroundings. The term 'patera' is used for deep, complex or irregularly shaped volcanic craters such as the Hadriaca Patera and Tyrrhena Patera at the north-eastern margin of the Hellas impact basin. However, despite its name and the fact that it is positioned near volcanoes, the actual origin of Orcus Patera remains unclear. (ESA/DLR/FU Berlin - G. Neukum)

return to Earth, a NASA landing system, and a NASA launch vehicle. These activities are designed to serve as the foundation of a cooperative program to increase science returns and move the agencies toward a joint Mars sample return mission in the 2020s.

Mars's mysterious elongated crater

Orcus Patera (above) is an enigmatic elliptical depression near Mars's equator, in the eastern hemisphere of the planet. Located between the volcanoes of Elysium Mons and Olympus Mons, its formation remains a mystery. Often overlooked, this well-defined depression extends approximately 380 by 140 kilometres in a NNE–SSW direction. It has a rim that rises up to 1800 metres above the surrounding plains, while the floor of the depression lies 400–600 metres below the surroundings.

The term 'patera' is used for deep, complex or irregularly shaped volcanic craters such as the Hadriaca Patera and Tyrrhena Patera at the north-eastern margin of the Hellas impact basin. However, despite its name and the fact that it is positioned near volcanoes, the actual origin of Orcus Patera remains unclear.

Aside from volcanism, there are a number of other possible origins. Orcus Patera may be a large and originally round impact crater, subsequently deformed by compressional forces. Alternatively, it could have formed after the erosion of aligned impact craters. However, the most likely explanation is that it was made in an oblique impact, when a small body struck the surface at a very shallow angle, perhaps less than five degrees from the horizontal.

The existence of tectonic forces at Orcus Patera is evident from the presence of the numerous 'graben', rift-valley-like structures that cut across its rim. Up to 2.5 kilometres wide, these graben are oriented roughly east–west and are only visible on the rim and the nearby surroundings. Within the Orcus Patera depression itself, the large graben are not visible, probably having been covered by later deposits. But smaller graben are present, indicating that several tectonic events have occurred in this region and also suggesting that multiple episodes of deposition have taken place.

The occurrence of 'wrinkle ridges' within the depression proves that not only extensional forces, as would be needed to create graben, but also compressive forces shaped this region. The dark shapes near the centre of the depression were probably formed by wind-driven processes, where dark material excavated by small impact events in the depression has been redistributed. However, the presence of graben and wrinkle-ridges has no bearing on the origin of Orcus Patera, as both can be found all over Mars. The true origin of Orcus Patera remains an enigma.

Hibernating Mars rover may not call home

NASA mission controllers have not heard from the Mars Exploration Rover Spirit since 22 March, and the rover is facing its toughest challenge yet - trying to survive the harsh Martian winter. The rover team anticipated Spirit would go into a low-power "hibernation" mode since the rover was not able to get to a favorable slope for its fourth Martian winter, which runs from May through November. The low angle of sunlight during these months limits the power generated from the rover's solar panels.

During hibernation, the rover suspends communications and other activities so available energy can be used to recharge and heat batteries, and to keep the mission clock running.

On 26 July, mission managers began using a paging technique called "sweep and beep" in an effort to communicate with Spirit. "Instead of just listening, we send commands to the rover to respond back to us with a communications beep," said John Callas, project manager for Spirit and its twin, Opportunity, at NASA's Jet Propulsion Laboratory in Pasadena, Calif. "If the rover is awake and hears us, she will send us that beep."

Based on models of Mars' weather and its effect on available power, mission managers believe that if Spirit responds, it most likely will be in the next few months. However, there is a very distinct possibility Spirit may never respond. "It will be the miracle from Mars if our beloved rover phones home," said Doug McCuistion, director of NASA's Mars Exploration Program in Washington. "It's never faced this type of severe condition before - this is unknown territory."

Because most of the rover's heaters were not being powered this winter, Spirit is likely experiencing its coldest internal temperatures yet -- minus 55 degrees Celsius. During three previous Martian winters, Spirit communicated about once or twice a week with Earth and used its heaters to stay warm while parked on a sun-facing slope for the winter. As a result, the heaters were able to keep internal temperatures above minus 40 degrees Celsius.

Spirit is designed to wake up from its hibernation and communicate with Earth when its battery charge is adequate. But if the batteries have lost too much power, Spirit's clock may stop and lose track of time. The rover could still reawaken, but it would not know the time of day, a situation called a "mission-clock fault." Spirit would start a new timer to wake up every four hours and listen for a signal from Earth for 20 minutes of every hour while the sun is up.

The earliest date the rover could generate enough power to send a beep to Earth was calculated to be around 23 July. However, mission managers don't anticipate the batteries will charge adequately until late September to mid-October. It may be even later if the rover is in a mission-clock fault mode. If Spirit does wake up, mission managers will do a complete health check on the rover's instruments and electronics.

Based on previous Martian winters, the rover team anticipates the increasing haziness in the sky over Spirit will offset longer daylight for the next two months. The amount of solar energy available to Spirit then will increase until the southern Mars summer solstice in March 2011. If we haven't heard from it by March, it is unlikely that we will ever hear from it. "This has been a long winter for Spirit, and a long wait for us," said Steve Squyres, the principal investigator for NASA's two rovers who is based at Cornell University, Ithaca, N.Y. "Even if we never heard from Spirit again, I think her scientific legacy would be secure. But we're hopeful we will hear from her, and we're eager to get back to doing science with two rovers again."

Spirit and its twin, Opportunity, began exploring Mars in January 2004 on missions planned to last three months. Spirit has been nearly stationary since April 2009, while Opportunity is driving toward a large crater named Endeavour. Opportunity covered more distance in 2009 than in any prior year. Both rovers have made important discoveries about wet environments on ancient Mars that may have been favorable for supporting microbial life.

Video camera will show Mars rover's touchdown

A downward-pointing camera on the front-left side of NASA's Curiosity rover will give adventure fans worldwide an unprecedented sense of riding a spacecraft to a landing on Mars. The Mars Descent Imager, or MARDI, will start recording high-resolution video about two minutes before landing in August 2012. Initial frames will glimpse the heat shield falling away from beneath the rover, revealing a swath of Martian terrain below illuminated in afternoon sunlight. The first scenes will cover ground several kilometres across. Successive images will close in and cover a smaller area each second.

The full-colour video will likely spin, then shake, as the Mars Science Laboratory mission's parachute, then its rocket-powered backpack, slow the rover's descent. The left-front wheel will pop into view when Curiosity extends its mobility and landing gear. The spacecraft's own shadow, unnoticeable at first, will grow in size and slide westward across the ground. The shadow and rover will meet at a place that, in the final moments, becomes the only patch of ground visible, about the size of a bath towel and underneath the rover. Dust kicked up by the rocket engines during landing may swirl as the video ends and Curiosity's surface mission can begin.

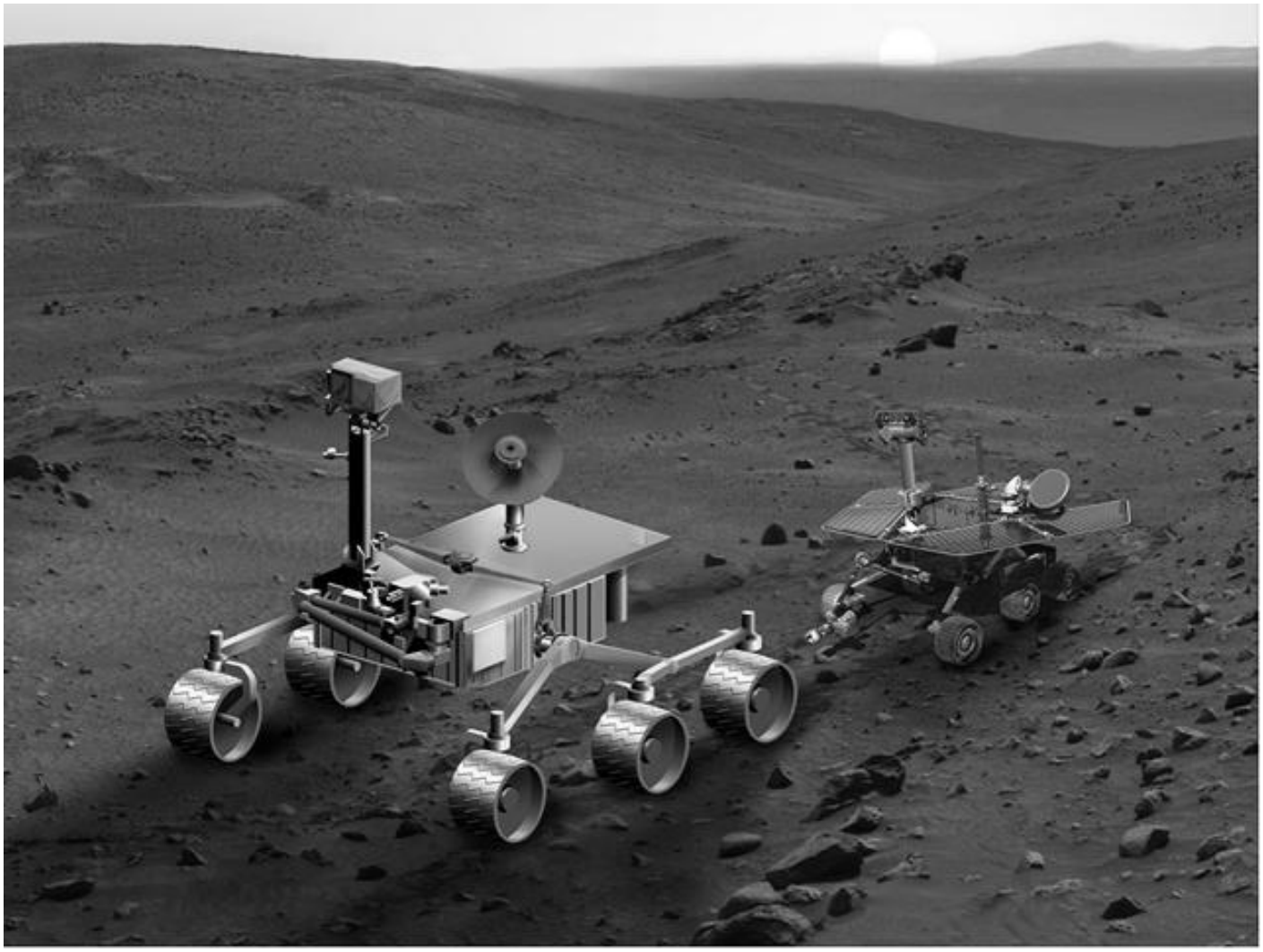
All of this, recorded at about four frames per second and close to 1,600 by 1,200 pixels per frame, will be stored safely into the Mars Descent Imager's own flash memory during the landing. But the camera's principal investigator, Michael Malin of Malin Space Science Systems, San Diego, and everyone else will need to be patient. Curiosity will be about 250 million kilometres from Earth at that point. It will send images and other data to Earth via relay by one or two Mars orbiters, so the daily data volume will be limited by the amount of time the orbiters are overhead each day.

"We will get it down in stages," said Malin. "First we'll have thumbnails of the descent images, with only a few frames at full scale." Subsequent downlinks will deliver additional frames, selected based on what the thumbnail versions show. The early images will begin to fulfill this instrument's scientific functions. "I am really looking forward to seeing this movie. We have been preparing for it a long time," Malin said. The lower-resolution version from thumbnail images will be comparable to a YouTube video in image quality. The high-definition version will not be available until the full set of images can be transmitted to Earth, which could take weeks, or even months, sharing priority with data from other instruments."

The Mars Descent Imager will provide the Mars Science Laboratory team with information about the landing site and its surroundings. This will aid interpretation of the rover's ground-level views and planning of initial drives. Hundreds of the images taken by the camera will show features smaller than what can be discerned in images taken from orbit.

"Each of the 10 science instruments on the rover has a role in making the mission successful," said John Grotzinger of the California Institute of Technology in Pasadena, chief scientist for the Mars Science Laboratory. "This one will give us a sense of the terrain around the landing site and may show us things we want to study. Information from these images will go into our initial decisions about where the rover will go."

The nested set of images from higher altitude to ground level will enable pinpointing Curiosity's location even before an orbiter can photograph the rover on the surface. Malin said, "Within the first day or so, we'll know where we are and what's near us. MARDI doesn't do much for six-month planning -- we'll use orbital data for that -- but it will be important for six-day and 16-day planning." In addition, combining information from the



Artist's impression shows the size difference between Curiosity and the current Spirit and Opportunity rovers (NASA)

descent images with information from the spacecraft's motion sensors will enable calculating wind speeds affecting the spacecraft on its way down, an important atmospheric science measurement. The descent data will later serve in designing and testing future landing systems for Mars that could add more control for hazard avoidance.

After landing, the Mars Descent Imager will offer the capability to obtain detailed images of ground beneath the rover, for precise tracking of its movements or for geologic mapping. The science team will decide whether or not to use that capability. Each day of operations on Mars will require choices about how to budget power, data and time.

In June 2010, spacecraft engineers and technicians re-installed the Mars Descent Imager onto Curiosity for what is expected to be the final time, as part of assembly and testing of the rover and other parts of the Mars Science Laboratory flight system at NASA's Jet Propulsion Laboratory, Pasadena, Calif. Besides the rover itself, the flight system includes the cruise stage for operations between Earth and Mars, and the descent stage for getting the rover from the top of the Martian atmosphere safely to the ground.

Malin Space Science Systems delivered the Mars Descent Imager in 2008, when NASA was planning a 2009 launch for the mission. This camera shares many design features, including identical electronic detectors, with two other science instruments the same company is providing for Curiosity: the Mast Camera and the Mars Hand Lens Imager. The company also provided descent imagers for NASA's Mars Polar Lander, launched in 1999, and Phoenix Mars Lander, launched in 2007. However, the former craft was lost just before landing and the latter did not use its descent imager due to concern about the spacecraft's data-handling capabilities during crucial moments just before landing.

Model helps search for Moon dust fountains

By Bill Steigerwald
NASA Goddard Space Flight Center

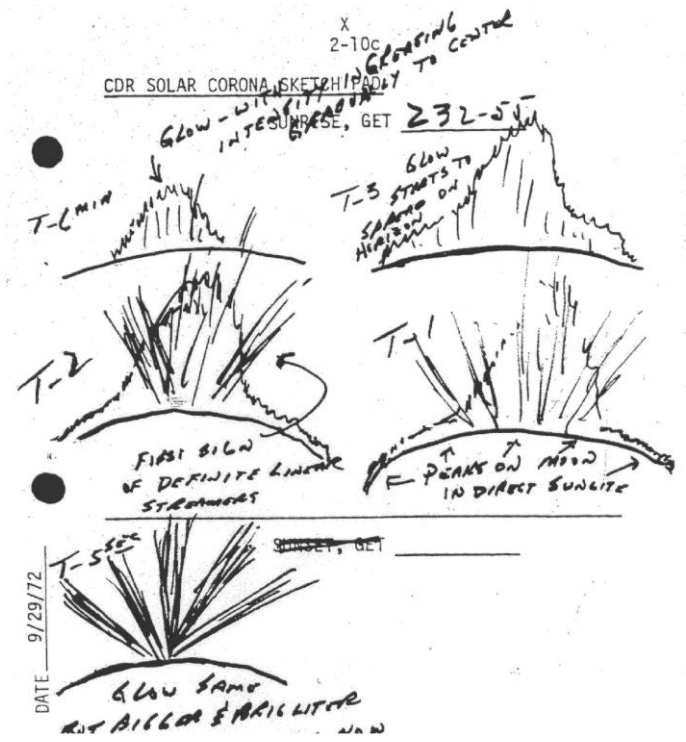
This is a picture of coronal and zodiacal light (CZL) taken with the Clementine spacecraft, when the sun was behind the moon. The white area on the edge of the moon is the CZL, and the bright dot at right is the planet Venus. (NASA)

In exploration, sometimes you find more than what you're looking for, including things that shouldn't be there. As the Apollo 17 astronauts orbited over the night side of the moon, with the sun just beneath the horizon right before orbital "sunrise," Eugene Cernan prepared to make observations of sunlight scattered by the sun's thin outer atmosphere and interplanetary dust from comets and collisions between asteroids. The idea was to have the moon block the brilliant direct sunlight so this faint glow, called Coronal and Zodiacal Light (CZL), could be seen. They should have seen a dim "hump" of light in the middle of the horizon that gradually grew in size and intensity until it was overwhelmed by sunrise. What came next was not supposed to happen.

Cernan did see the CZL glow, but it had a strange companion. A slim crescent of light appeared all along the horizon, and just before sunrise, faint rays appeared, similar to the columns of light seen on Earth when sunlight pokes through a hole in a layer of clouds. On Earth, the horizon glow seen at sunrise and sunset, and the rays, are created when sunlight scatters off atmospheric moisture and dust. But the moon has almost no atmosphere – its atmosphere is so thin, atoms and molecules there rarely collide with each other and it's technically referred to as an "exosphere". This thin atmosphere should not have produced the horizon glow seen.

The sighting during Apollo 17 was not just a one-time freak event. "Similar sightings were reported on Apollo 8, 10, and 15 during planned observations of coronal and zodiacal light," says Dr. Timothy Stubbs of NASA's Goddard Space Flight Center, Greenbelt, Md., and the University of Maryland, Baltimore County. "Lunar horizon glow (LHG) was first observed between 1966 and 1968 by TV cameras aboard the Surveyor landers – robotic precursors to the manned Apollo landings – specifically Surveyor 5, 6 and 7, and possibly Surveyor 1," adds Stubbs. While the Apollo observations detected LHG at high altitudes – eextending up to around 100 kilometres above the lunar surface, the LHG recorded by the Surveyors was much lower – within about a meter (one yard) of the surface, according to Stubbs.

Deepening the mystery is that LHG was not always seen. "The astronauts on Apollo 11, 12, and 14 did not look for CZL;



Apollo 17 astronaut Gene Cernan's sketch of the CZL glow (NASA)

however, similar CZL observations were made during Apollo 16 by Ken Mattingly, but no LHG or 'streamers' were seen (to his great personal disappointment). Analyses of coronal photographs from Apollo 15 and 17 revealed an 'excess brightness' along the lunar horizon, which was interpreted as LHG produced by sunlight scattering off a high altitude 'dust atmosphere'. Similar photographs taken during Apollo 16 did not contain any excess brightness (consistent with the astronaut observations). This indicates that LHG is a variable phenomenon – sometimes you see it, sometimes you don't," says Stubbs.

While dust can produce a LHG by scattering sunlight, the presence of even an intermittent high-altitude dust atmosphere was unexpected -- the moon's exosphere is far too thin for wind to blow and suspend dust. Although the moon is constantly bombarded by meteorites (mostly microscopic) that kick up dust, "the dust concentrations inferred from LHG are much higher than expected from debris ejected by meteorite impacts alone," adds Stubbs.

It has long been suggested that lunar dust gets transported electrically. For example, on the day side of the moon, solar ultraviolet radiation is strong enough to kick electrons from dust particles in the lunar soil. Removal of electrons, which have a negative electric charge, leaves the dust with a positive electric charge. Since like charges repel, the positively charged dust particles get pushed away from each other, and the only direction not blocked by more dust is up.

The smaller particles likely get ejected higher because they are lighter. This might explain the different LHG observed by Surveyor and Apollo. The low-altitude glow seen by Surveyor appeared to be from larger, relatively heavy particles, while the high-altitude glow seen by Apollo astronauts was likely from the smallest particles. Small particles can get such a boost from the surface charge that they are lofted high above the surface and follow ballistic trajectories, returning to the surface under the influence of the moon's gravity. This movement of the smallest particles could make fountains of moon dust.

However, much remains unknown about lunar dust and the LHG. "Only a handful of LHG observations have been made, so we really know very little about it," says Stubbs. "The uncertainties associated with previous observations are largely because the instruments used were designed to measure something else.

"The high altitude observations are particularly controversial. If LHG is present at high altitudes, then the suggestions are that it is produced either by sunlight scattering from dust, or by resonant scattering of sunlight from neutral sodium atoms in the exosphere. However, if sodium is producing the LHG, it should be seen up to altitudes in excess of 1,000 kilometres , but the LHG observed so far only appears to extend about 100 kilometres above the horizon. Our predictions indicate that the LHG observations appear to be more consistent with the presence of exospheric dust."

"It has been suggested that electrostatic forces play a role in the ejection of dust from the lunar surface, and its dynamics in the atmosphere, but we really don't understand how it gets there in such high abundances. So far, LHG has only been observed near the region where day transitions to night, called the terminator, but it could well be occurring elsewhere. This begs the question: Is LHG (from atmospheric dust) a global phenomenon or is it confined to the terminator region?

"We're still at the stage of determining whether or not LHG is really there – this is one of the major objectives of the LADEE mission," adds Stubbs.

As early as 2012, NASA could launch the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft that will orbit the moon and look for the LHG and exospheric dust hinted at in the Apollo observations. LADEE will look for LHG using the Ultraviolet Spectrometer (UVS) instrument, which will measure the intensity of light at different wavelengths at a point above the lunar horizon. Each potential source – sodium or dust, for example – will produce a unique "signature" glow in ultraviolet and/or visible light. LADEE may also be able to use its star-tracker navigation cameras to observe LHG, which would provide details on the shape of the visible light scattering sources, according to Stubbs. LADEE also has a dust detector instrument to record any hits from high-altitude dust.

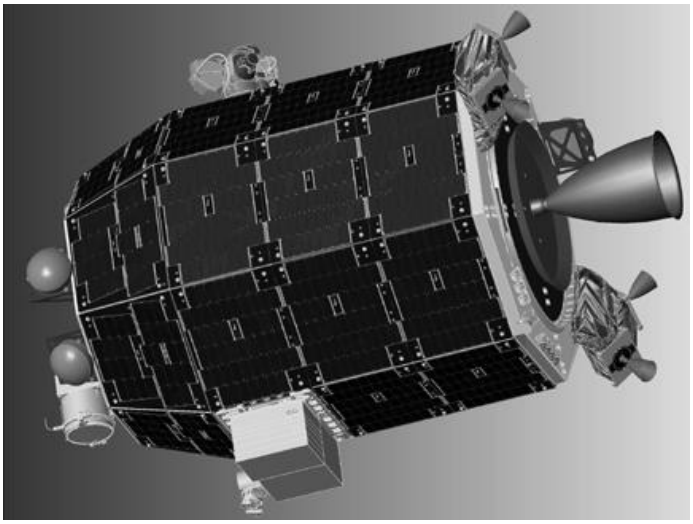
To give the LADEE mission an idea of the best techniques and places to look for the LHG, Stubbs and his team recently created computer simulations of dust and sodium-generated glows. "The simulations show that if LHG is produced by dust, then it will be brightest in the forward scattering direction; that is, with the dust between the sun and the observer," says Dr. David Glenar of New Mexico State University. "However, for this viewing geometry, the disk of the sun needs to be blocked (e.g., by the edge of the moon), so as not to be overwhelmed by its brightness. This is why LHG has previously only been observed from the shadow of the moon close to the terminator, and this is the initial approach that is planned for LADEE/UVS."

"This modeling is important as it reassures us that, based on previous observations, the LADEE/UVS ought to be able to observe LHG and distinguish it from other scattering sources; i.e., it can satisfy one of its prime mission objectives. This model will be a valuable tool for analyzing and interpreting the complicated UVS scattering data in the future," said Dr. Anthony Colaprete, NASA's Ames Research Center, Moffett Field, Calif., Principal Investigator for the LADEE/UVS instrument.

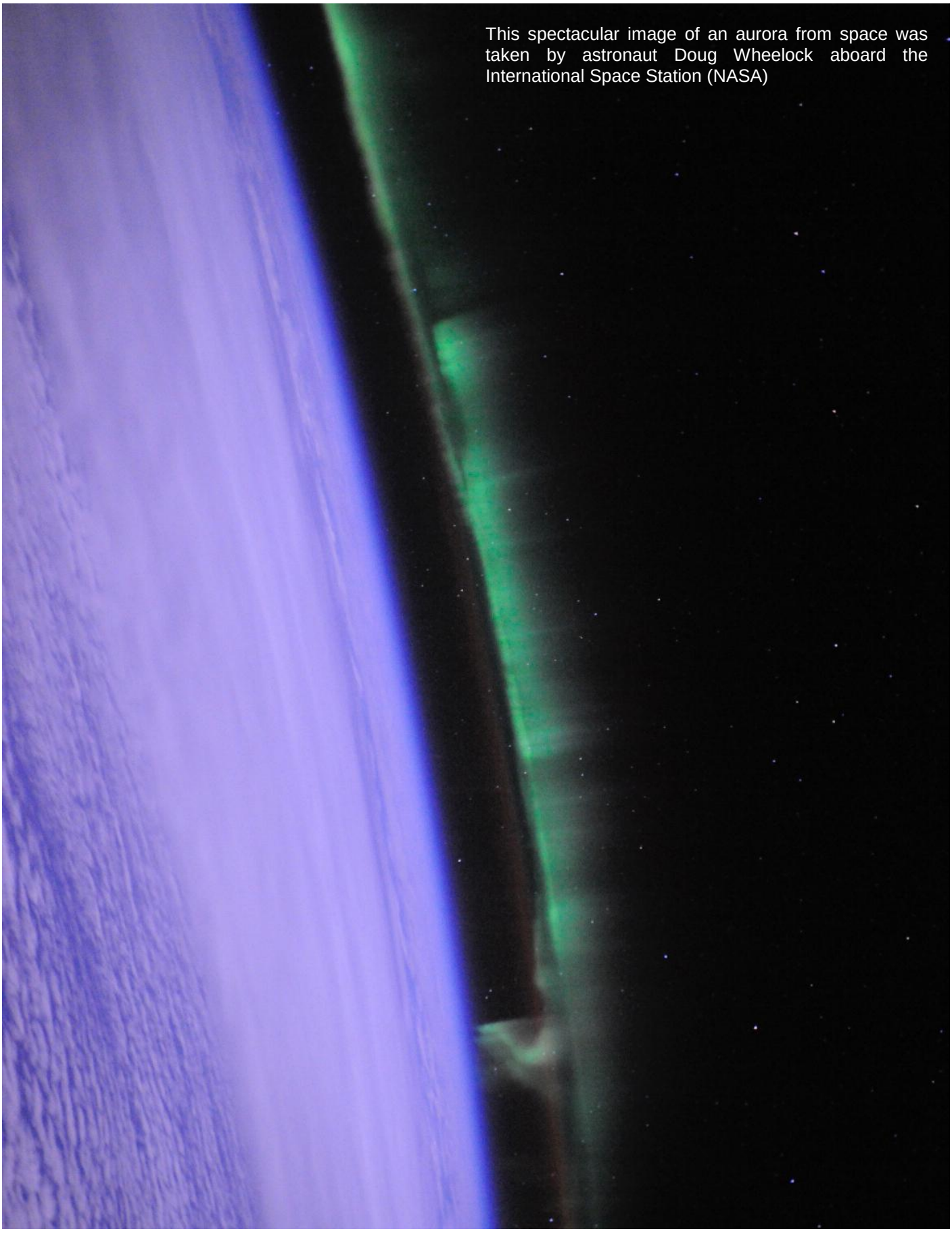
"Future developments of the model will include the capability to characterize the shape, size, and structure of the scattering dust grains, which will let us probe even further into the nature of the processes at work at the lunar surface," adds Dr. Denis Richard of NASA Ames and the San José State University Research Foundation.

Learning more about the strange lunar atmosphere with its potential fountains of sticky and abrasive moon dust is essential for future human exploration. "LHG could be telling us that the moon's atmosphere is much dustier than is typically thought. It was well-reported that the Apollo astronauts found lunar dust to be a significant nuisance when exploring the moon, and it's likely that these problems were exacerbated by electrostatic (static cling) effects. So a better understanding of the behavior of dust in the lunar environment would facilitate the development of more effective mitigation techniques," says Stubbs.

"The scattering of sunlight by dust in the lunar atmosphere could mean that the moon is not as good a location for sensitive astronomical observations as has previously been assumed. This characteristic of the lunar environment needs to be well characterized before an informed judgment regarding the benefit of lunar-based telescopes can be made," adds Stubbs.



LADEE – the Lunar Atmosphere and Dust Environment Explorer (NASA)



This spectacular image of an aurora from space was taken by astronaut Doug Wheelock aboard the International Space Station (NASA)