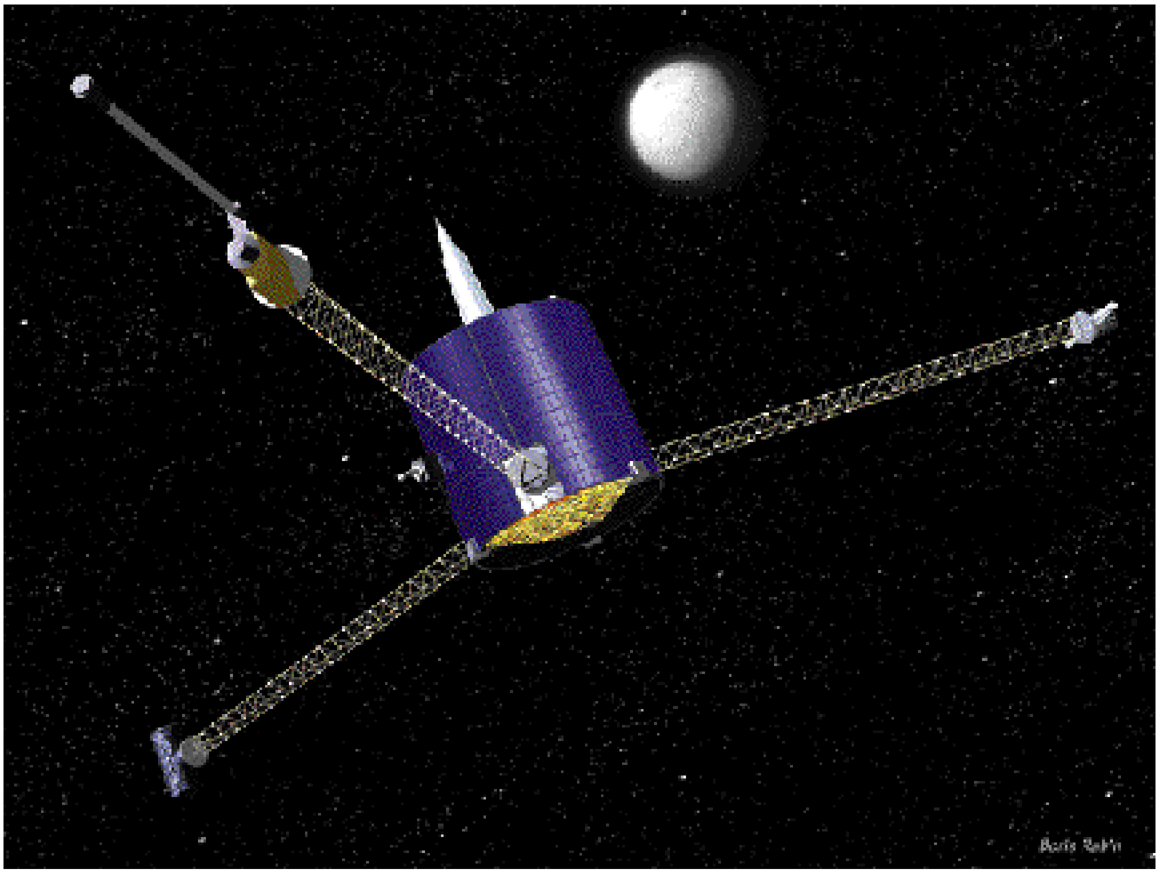
LUNAR PROSPECTOR

Mission Science Background

Press Kit

September, 1998



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Results taken from the seven science papers published in the September 4, 1998 issue of *Science.*

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Introduction

Lunar Prospector, the first dedicated lunar mission in 25 years, has already been a tremendous success. Following a near flawless launch on Jan 6, 1998, a four-day journey to the Moon and entry into lunar orbit, the tiny spin-stabilized spacecraft has been sending data back to Earth. Lunar data from the circular polar-mapping orbit has been arriving since January 15.

On March 5, 1998 Prospector scientists captured the public's imagination by announcing the discovery of a definitive signal for water ice at both of the lunar poles. At that time, a conservative analysis of the available data indicated that a significant quantity of water ice, possibly as much as 300 million metric tons, was mixed into the regolith (lunar soil) at each pole, with a greater quantity existing at the north pole. The first competitively selected Discovery class mission had conclusively demonstrated that, not only could a cost-capped, fast-development mission succeed, it could do ground-breaking science in the process.

The first operational gravity map of the Moon was announced at the same time. Since then, Lunar Prospector engineer's have taken advantage of the missions own science results and the gravity data have been used to facilitate orbit maintenance.

With nearly two thirds of Prospector's one-year primary mission completed, the most recent look at Prospector's data reveals several remarkable insights into lunar science and resources.

Mission Profile

At 9:28 p.m. (EST) on January 6, 1998, Lunar Prospector (LP) blasted off to the Moon aboard a Lockheed Martin solid-fuel, three-stage rocket called Athena II. It was successfully on its way to the Moon for a one-year, polar orbit, primary mission dedicated to globally mapping lunar resources, gravity, and magnetic fields, and even outgassing events. About 13 minutes after launch, the Athena II placed the Lunar Prospector payload into a "parking orbit" 115 miles above the Earth. Following a 42-minute coast in the parking orbit, Prospector's Trans Lunar Injection (TLI) stage successfully completed a 64-second burn, releasing the spacecraft from Earth orbit and setting it on course to the Moon, a 105-hour coast. The official mission timeline began when the spacecraft switched on 56 minutes, 30 seconds after liftoff. Shortly after turning the vehicle on, mission controllers deployed the spacecraft's three extendible masts, or booms. Finally, the spacecraft's five instruments -- the gamma-ray spectrometer, alpha particle spectrometer, neutron spectrometer, magnetometer and electron reflectometer -- were turned on. On Sunday, January 11, at 7:20 a.m. (EST), Lunar Prospector was successfully captured into lunar orbit, and a few days later began its mission to globally map the Moon.

Lunar Prospector is a small,* spin-stabilized spacecraft in a polar orbit with a period of 118 minutes at a nominal altitude of 100 km (63 miles). Since the Moon rotates a full turn beneath the spacecraft every lunar cycle (~27.3 days) as it zips around the Moon every 2 hours, Prospector visits a polar region every hour and completely covers the lunar surface twice a month. Prospector's one-year-long primary mission with an optional extended mission of a further 6 months at an even lower altitude enables large amounts of data to collect over time. For some science instruments, a significant amount of time is required to obtain high quality usable data. Thus, Prospector's polar orbit and long-mission time render it ideal from the standpoint of globally mapping the Moon.

*(1.3m in diameter X 1.4m tall bus with three 2.5 meter science masts carrying its five science instruments and isolating them from the spacecraft's electronics)

Lunar Prospector Scientific Goals

As a Discovery-class mission, Prospector's scientific goals were carefully chosen to address outstanding questions of lunar science both efficiently and effectively. In the Post-Apollo era, NASA convened the Lunar Exploration Science Working Group (LExSWG) to draft a list of the most pressing, unanswered scientific riddles still facing the lunar-science community. In 1992, LExSWG produced a document, entitled "A Planetary Science Strategy for the Moon." The following lunar science objectives were listed: How did the Earth-Moon system form? How did the Moon evolve? What is the impact history of the Moon's crust? What constitutes the lunar atmosphere? What can the Moon tell us about the history of the Sun and other planets in the Solar System?

Lunar Prospector mission designers carefully selected a set of objectives and a payload of scientific instruments which would address as many of LExSWG's priorities as possible, while remaining within the tight budget confines of NASA's "faster, better, cheaper" Discovery Program.

Lunar Prospector's identified critical science objectives are:

⇒ "Prospect" the lunar crust and atmosphere for potential resources, including minerals, water ice and certain gases,

⇒ Map the Moon's gravitational and magnetic fields, and

⇒ Learn more about the size and content of the Moon's core.

The six experiments (five science instruments) which address these objectives are:

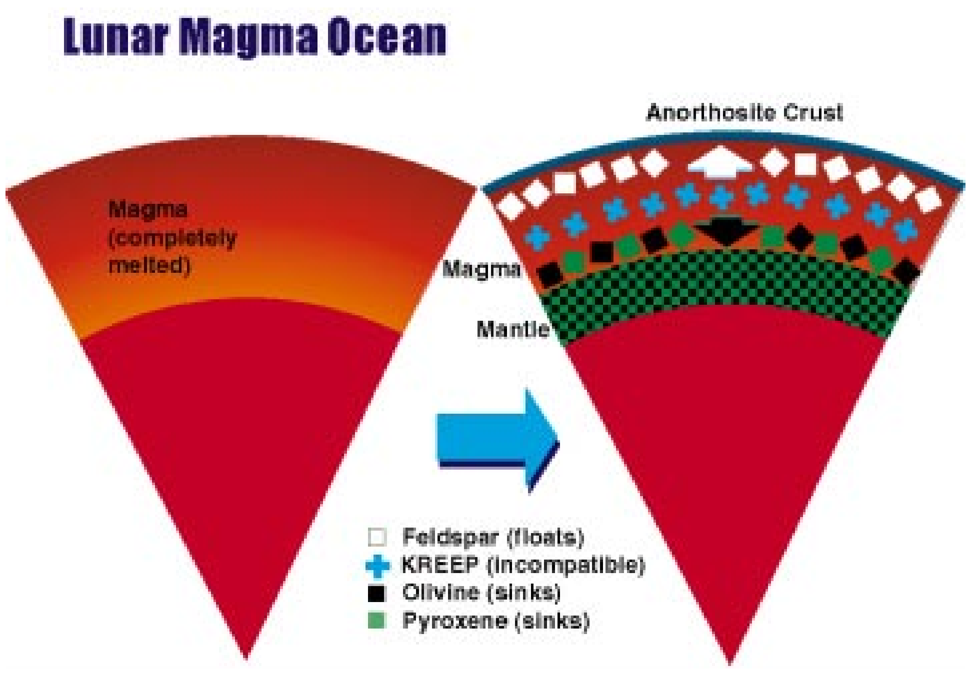
- Neutron Spectrometer (NS) -- Map hydrogen using neutrons having several different energy ranges and thereby infer the presence or absence of water.
- ♦ Gamma Ray Spectrometer (GRS) -- Map 10 key elemental abundances, several of which offer clues to lunar formation and evolution.
- ♦ Magnetometer/Electron Reflectometer (Mag/ER) -- These two experiments combine to measure lunar magnetic field strength at the surface and at the altitude of the spacecraft and thereby greatly enhance understanding of lunar magnetic anomalies.
- ♦ Doppler Gravity Experiment (DGE) -- Make an operational gravity map of the Moon for use by future missions as well as LP by mapping gravity field measurements from changes in the spacecraft's orbital speed and position.
- ♦ Alpha Particle Spectrometer (APS) -- Map out-gassing events by detecting Radon gas (current outgassing events) and Polonium (tracer of recent, i.e. 50 years).

THE BASICS OF LUNAR SELENOLOGY (GEOLOGY)

Formation

The current most widely held theory of how the Moon was formed is the impact theory. This theory suggests that a large body, possibly the size of Mars impacted the Earth some 4 billion years ago and the material which was thrown off, a combination of Earth material and the impactor, coalesced into Earth's Moon. The body was originally molten. As it cooled, light elements such as calcium and aluminum and silica crystallized into feldspar and other minerals and floated upwards. Heavier minerals such as iron and magnesium-rich olivine and pyroxene formed and sank downward forming the lunar mantle. Incompatible elements such as KREEP (Phosphorous-K, Rare Earth Elements, and Potassium) were trapped between the layers. Repeated large impacts on the lunar surface itself, around 4.1 to 3.9 billion years ago, formed craters which gradually filled with basaltic lava. These include the large dark areas that can be seen from Earth, the maria such as Mare Tranquilitatus-the Sea of Tranquillity and Mare Imbrium-the Sea of Rains. Over time, the Moon has continued to be bombarded from space by crater forming impacts. As the Moon cooled, however, lava ceased to fill the craters, and the impacts began to "garden" or break up the brittle lunar surface, creating the powdery dust which is known as regolith or lunar "soil."

Lunar topography can be roughly divided into two main types -- the maria with their distinctive dark color, and the highlands which are significantly different in composition.



A model diagram of the formation of the lunar crust, showing an incompatible KREEP layer trapped between the mantle and the crust.

APPROACHES TO LUNAR SCIENCE AND PREVIOUS MISSIONS

Experiment Type (*= aboard LP)	**Previous lunar missions**
Photographic Studies	U.S. Missions: Lunar Orbiter 1-5, Surveyor 1, Surveyor 3, Surveyor 5-7, Ranger 7-9, Apollo 8, Apollo 10-17, Clementine Soviet missions: Luna 3, Luna 9, Luna 12-13, Luna 16-17, Luna19-22, Zond 3, Zond 6-8
Surface Sampling/Soil Analysis	U.S Missions: Surveyor 3, Surveyor 5-7, Apollo 11-12, Apollo 14-17 Soviet Missions: Luna 16-17, Luna 20-21, Luna 24
Magnetic Studies*	U.S. Missions: Apollo 12, Apollo 14-17Soviet Missions: Luna 10, Luna 21-22
Gravity Studies*	U.S. Missions: Apollo 12, Apollo 14-17, Clementine Soviet Missions: Luna 10-11, Luna 14, Luna 19, Luna 22
Alpha Particle Spectroscopy*	U.S. Missions: Apollo 15-16
Gamma-Ray Spectroscopy*	U.S. Missions: Apollo 15-16 Soviet Missions: Luna 10-11, Luna 22
Neutron Spectroscopy*	U.S. Missions: none, although Apollo 17 had a "neutron probe"

Photographic Experiments

Ground-based astronomy provided early views of the Moon's near side, the side that perpetually faces the Earth. In addition, thirty-eight previous lunar missions have photographed the Moon, supplying scientists with a plethora of still imagery and television footage of the lunar surface. In 1959, the Soviet’s Luna 3 spacecraft was the very first to capture a full composite view of the far side of the Moon. During the 1960s and 1970s, NASA successfully flew 22 missions to the Moon, including the historic Apollo missions. The Soviets sent another 20. Throughout the 1960s and 1970s, these missions continued to amass images of the Moon and, in 1965, the American public watched for the first time live pictures transmitted from NASA’s Ranger 9 spacecraft. Cameras aboard NASA’s Lunar Orbiter 1 spacecraft took the first pictures of Earth from the Moon. All of the Apollo missions returned lunar photographs to Earth; even the failed Apollo 13 mission yielded a limited amount of photographic data. The U.S. Department of Defense Clementine spacecraft, which briefly orbited the Moon in 1994 obtained a significant set of lunar imagery. The polar orbit was an ellipse, roughly 400 kilometers above the surface at the closest point. The payload aboard Clementine was a camera and a topographic mapper.

Lunar Prospector's Design Philosophy

Lunar Prospector was never intended to carry a camera, nor does it require a true onboard computer for two key reasons. Prospector, from its inception, was designed to be a simple, cost-efficient spacecraft. Cameras require pointing in a given direction. The Lunar Prospector spacecraft is spin-stabilized, an engineering strategy that is well understood, highly successful and simple and cheap to achieve. With a camera, Prospector would have required a whole different engineering strategy, as well as a computer to control the camera. The result would have been a far more complex, heavier, costlier spacecraft that may well not have survived the Discovery selection process. Secondly, Lunar Prospector is a science-focused mission. That is, Prospector was designed to answer the highest-priority outstanding questions the planetary science community still has about the Moon. The spacecraft's five instruments were chosen according to that criterion. Previous Moon missions have, in fact, taken thousands of pictures of the Moon. We already have quite detailed knowledge of what the Moon looks like. What we don't yet know are details about its composition, volcanic activity, magnetic and gravitational fields and/or its resources.

Lunar Sampling/Soil Analysis Experiments

The first spacecraft to dig into the soil of an extraterrestrial body (which happened to be the Moon) was NASA's Surveyor 3, which landed on a geographic region of the Moon called the Oceanus Procellarum in April 1967. Over the next several months, each of the Surveyor landers (5-7) probed the lunar surface with instruments called alpha-scattering surface analyzers and soil mechanics surface samplers. Each was designed to physically probe the lunar soil and gather measurements about the abundances of the various elements that constitute lunar rocks and soil. Data gathered with these two instruments was valuable, but limited in the sense that only specific regions of the Moon were analyzed (the landing sites). Some of the Soviet missions also excavated lunar samples for further analyses on Earth.

All of the Apollo landers (11-17), with the exception of the failed Apollo 13, performed experiments with lunar surface samples. With tools such as hammers, scoops, rakes and tongs, the Apollo astronauts collected many lunar rock samples and performed a series of tests on the mechanics of the lunar soil. In addition, they returned over 800 ponds of lunar rock to Earth to enable further detailed study.

Lunar Prospector's Approach

Lunar Prospector, a polar-orbiting spacecraft, will not touch down on the lunar surface during either its primary (first year) or extended mission (up to an additional six months after that, until its fuel supply runs out). While previous lunar landing missions have returned an immense amount of physical data, the main limitation of the experiments thus far is applicability to the Moon as a whole. Lunar soil and rocks at the Moon's equator, where the majority of such experiments have been conducted tell a limited story. Global elemental abundances need to be determined. Until Prospector's confirmation of polar water ice, that valuable resource and potential sample was not seriously considered as the basis for a sample return mission. Before a future sample return mission can be contemplated, it is necessary to have an understanding of the entire global situation in order to profitably plan such a mission. Hence, over time, scientists rely on data from both orbiters, such as LP and landers, to completely understand a planet and develop an approach to its study.

Remote Sensing Experiments

In contrast to direct geologic studies of actual lunar rocks and soil, remote sensing experiments analyze the lunar surface and atmosphere from a distance. Photography is, of course, a kind of remote sensing study, one with which we are familiar. Spectroscopy, however, provides information not discernible to the human eye. Using gamma-ray spectroscopy, Apollo 15 and 16 were the first missions to attempt to measure the concentrations of elements that make up the lunar crust using spectroscopy. (A primitive version of the Apollo GRS was flown aboard the Soviet's Luna 10 spacecraft in 1966, but this instrument gathered only limited data). The general findings from the Apollo 15/16 GRS experiment indicated that there are two distinct geographic regions of the Moon -- the highlands and the mare -- with chemical compositions that are, in fact, markedly different (for example, iron and magnesium being relatively enriched in the mare). Those data also indicated that the concentrations of certain other elements, such as thorium and titanium, are non-uniformly distributed and that the far side of the Moon differs from the near side.

The Apollo 15/16 GRS acquired data on the abundance of four elements -- thorium, potassium, iron, and titanium -- near the equatorial region of the Moon. In concert, the landing modules for those missions collected samples from the same region, permitting comparison of chemical composition data acquired via remote sensing techniques (GRS) and direct sampling (mass spectrometry of soil and rock samples). Lunar Prospector mission scientists, of course, will not be able to conduct similar studies comparing in situ samples with remotely acquired data, however, global coverage offers insights not achievable with single point investigations. In addition, because we do have an existing store of lunar rock, LP data is being compared to these samples and may reveal important information.

Lunar Prospector's Role

Since Lunar Prospector is an orbiting spacecraft, its entire science payload consists of remote sensing instruments, three spectrometers and the two magnetic field instruments. As with any form of spectroscopy, the quality of the data improves with the time of sampling (number of counts detected). Statistically, it is very important for mission scientists to continually gather spectral information over the same lunar surface regions in order to subtract-out background “noise” caused by not only the cosmic environment but also by the elements which make up the materials on the spacecraft and the instruments themselves. However, with LP, interference from the spacecraft and its electronics are kept to a minimum by the fact that the instruments are separated from the body of the vehicle by eight-foot booms.

Using spectroscopy and other remote sensing techniques, the Prospector mission can perform global-mapping studies not possible with landing craft, such as were typical of the Apollo series of missions. For the scientific community, such an approach represents the logical next step in lunar exploration. Depending upon what Prospector finds, future lunar landers may someday return to the Moon to more thoroughly investigate specific sites, say at the ‘icy’ lunar poles.

LUNAR PROSPECTOR'S EXPERIMENTS

Background

When planning the Lunar Prospector mission, designers chose six experiments which would most closely fulfill the priorities outlined by LExSWG, while at the same time being sufficiently economical to meet the stringent budgeting requirements of the Discovery Program. Five instruments aboard Prospector are conducting six experiments. Three spectrometers (gamma-ray, alpha-particle and neutron) are globally mapping the Moon's surface and tenuous atmosphere (consisting mainly of gas release events) to determine which minerals and gases are present, and in what abundancy. Two instruments, the magnetometer and electron reflectometer, are measuring the Moon's anomalous magnetic properties, and in doing so, beginning to characterize the nature and size of a possible lunar core. Finally, the vehicle's own telemetry (communication system) serves as the "instrument" for Lunar Prospector's Doppler Gravity Experiment, which is globally mapping the Moon's non-uniform gravitational fields.

Why Use Spectroscopy?

Physicists use spectroscopy for a variety a research pursuits. A rather general term, spectroscopy is nothing more than the process of visualizing a substance by splitting its light and other emissions into their constituent parts. One of the simplest spectra to consider is a rainbow: visible light is dispersed into its different energies (called wavelengths) when it passes through droplets of rainwater in the atmosphere. Each wavelength absorbs (and thus reflects) a different color, which is readily apparent to the naked eye. This is so because each wavelength has a characteristic energy level. Spectrometers are instruments which record such dispersions of energy, called spectra.

Since it is no trivial matter to collect rocks and soil samples from other planets, break them up into their individual elements and thereby determine their chemical makeup, spectrometers play a major role in planetary exploration. Knowing what planets, asteroids and moons are made of helps scientists piece together the history and evolution of the Solar System. One type of spectroscopy, gamma-ray spectroscopy, is a technique in which scientists can measure (from orbit) the composition of surface material (down to several inches) around any celestial body possessing little or no atmosphere (such as is the case for the Moon or for Mars, for instance).

The way all of Lunar Prospector's three spectrometers work is by detecting (remotely, from orbit) "signature" energies emitted by various elements in the lunar soil and atmosphere. Such energy emitted by the Moon comes from two sources: "natural" radiation and "induced" radiation. Just like on Earth, certain elements are naturally radioactive and give off radiation (energy) on a constant basis. Other elements, while not naturally radioactive, also emit energy, but in response to constant bombardment of the Moon's surface by galactic and solar cosmic radiation. This is induced radiation.

Unlike Earth, which has a thick, protective atmosphere, the Moon is recipient to most, if not all, passing solar and cosmic energy causing many interactions. The key to spectroscopy's value is that each element emits a unique level of energy. By using a spectrometer, planetary scientists can discern the chemical makeup of the surface of a planet by looking for signature "peaks" (in energy emission) of an energy output plot -- an identifying barcode of sorts for the actual elements which make up the crust and atmosphere. Because solids and gases emit vastly different levels of energy, spectrometers are usually calibrated to detect ranges of energies. Each of

Prospector’s three spectrometers “sees” a characteristic energy range, permitting the detection of energy particles such as fairly-low-energy neutrons (the neutron spectrometer’s range of detection is from less than 0.3 eV [electron volts] to hundreds of keV [thousand electron volts]), high-energy gamma rays (the gamma-ray spectrometer’s range of detection is ~0.3 MeV [million electron volts] to 9 MeV), higher energy neutrons (a portion of the gamma-ray spectrometer is used to detect neutrons with energies from 0.5 MeV to 9.5 MeV) and alpha particles (the alpha particle spectrometer’s range of detection is ~4.1 MeV to 6.6 MeV).

Gamma-Ray Spectroscopy

Lunar Prospector's gamma-ray spectrometer (GRS) is mapping the abundances of ten elements on the Moon's surface:

thorium (Th)

potassium (K)

uranium (U)

iron (Fe)

oxygen (O)

silicon (Si)

aluminum (Al)

calcium (Ca)

magnesium (Mg)

titanium (Ti)

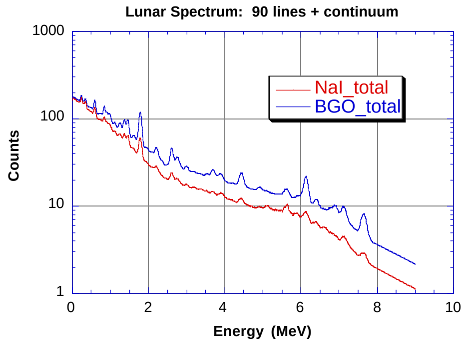
The GRS is especially sensitive to the heavy, radioactive element thorium and the lighter element potassium. These elements are particularly plentiful in the part of the crust that is last to solidify. Thus, mission scientists are able to determine the global distribution of KREEP (K-potassium, Rare Earth Elements, and P-phosphorous), a chemical "tracer" of sorts which helps to tell the story of the Moon's volcanic and impact history. The data produced by the GRS are helping scientists to understand the origins of the lunar landscape, and may also tell future explorers where to find useful metals like aluminum and titanium.

How Lunar Prospector's GRS Works

A gamma ray is a very energetic photon (a tiny parcel of light) -- more energetic than a visible light ray or an X-ray. When gamma rays reach the orbiting Lunar Prospector spacecraft, they pass through a crystal of bismuth germanate (BGO crystal) in the GRS.

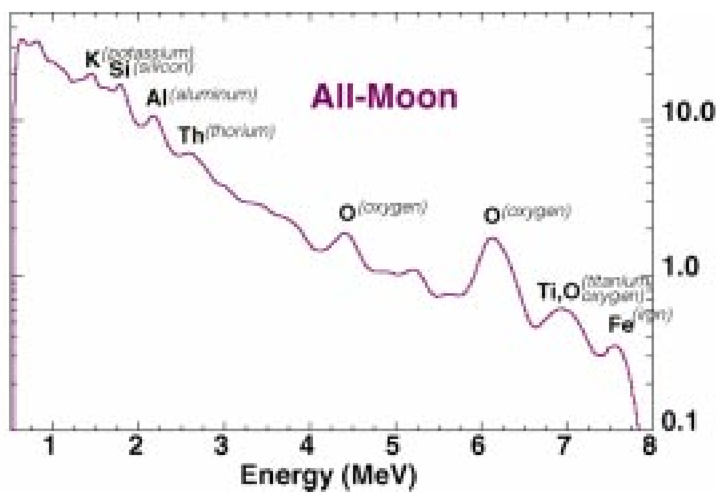
The various atoms inside this detector give off a flash of light when the radiation hits them;. Gamma-ray photons with high energies produce brighter flashes than gamma-ray photons with low energies. The light produced by the gamma-ray is then measured by a photomultiplier tube (PMT) which converts the light signal into an amplified electronic signal. Finally, this electronic signal is sent back to Earth for scientists to analyze. The energy of a given gamma ray tells scientists exactly which kind of atom emitted it.

To fully appreciate the potential of LP's GRS, a useful comparison can be drawn with the earlier Apollo GRS experiments. In contrast to Lunar Prospector, which is mapping the elemental composition of the entire lunar surface, the mapping performed by Apollo 15 and 16 only covered about 20 percent of the lunar surface -- specifically, the region around the Moon's mid-portion or equator. Another difference between the Apollo-era and recent Lunar Prospector gamma-ray spectroscopy studies is the detecting crystal inside the GRS instrument itself. The Apollo 15/16 instrument used a sodium iodide (NaI) crystal, whereas Lunar Prospector's crystal is composed of bismuth, germanium, and oxygen atoms (BGO crystal).



A comparison of simulations of an Apollo GRS spectrum and the LP GRS spectrum.

Since the combined atomic weight of bismuth, germanium and oxygen exceeds that of sodium and iodine, a BGO crystal is significantly denser than an NaI crystal. As a result, a BGO crystal is better able to stop gamma rays in their tracks and, as such, offers greater detection sensitivity -- on the order of two- to eight-fold higher -- than an NaI crystal. What that means is that energy spectra measured with a BGO crystal can be more cleanly separated (lines can be more easily distinguished from one another on an energy plot) than spectra measured with a NaI crystal (see accompanying graphic). In addition, certain elements which were unmappable by the Apollo GRS, such as uranium, aluminum, calcium and magnesium, can be detected with Lunar Prospector's more sensitive instrument. This offers mission scientists more opportunities to distinguish subtle features of the lunar landscape. The ability to measure concentrations of aluminum and calcium, for instance, may unearth clues as to the makeup of certain types of highland rock formations. Similarly, the distribution of titanium serves as a useful "probe" for mare regions. Other geochemical clues to planetary evolution include the presence of iron stores, the ratio of iron oxide (FeO) to magnesium oxide (MgO), the ratio of potassium to uranium (which hints at remelting rates of primordial condensates), and the ratio of thorium (Th) to uranium, which serves as a marker for the relative abundance of volatile compounds.



Sample data plot from Lunar Prospector's gamma-ray spectrometer

While gamma-ray data are highly informative, relatively few gamma-rays leave the Moon's surface and escape into space. Much as a camera working in conditions of low light can compensate by increasing exposure time, gamma ray spectroscopy generally benefits from a significantly long detection period, allowing spectral lines to fill in over time. One sweep -- or even a few sweeps -- over the Moon's surface would not give mission scientists enough information to determine the concentration of radioactive elements. In addition, the stable (non-radioactive) elements do not emit gamma rays as readily as do naturally radioactive ones, so it will take Lunar Prospector up to a year or more to collect enough data to estimate the concentrations of these elements. After a year of mapping, mission controllers expect to drop Prospector's orbiting altitude to as low as 6 miles (10 km) above the lunar surface, where the spacecraft will remain until it runs out of fuel. The GRS experiment will continue to benefit from the extra time and lower altitude.

The GRS also contributes indirectly to the search for water on the Moon. The bismuth germanate crystal is surrounded by a shield of borated plastic (anti-coincidence shield) that detects high-energy (fast) neutrons. The main purpose of this shield is to allow correction for background signal caused by solar and galactic cosmic rays. It differentiates between gamma rays and the cosmic ray background. In addition, because it is borated, it also measures fast (high energy) and epithermal (medium-energy) neutron fluxes. Mission scientists are using this information, in concert with the lower-energy (thermal and epithermal) neutron counts detected by Lunar Prospector's neutron spectrometer, to detect water ice at the lunar poles.

ALPHA-PARTICLE SPECTROSCOPY

The Apollo series of missions revealed that the Moon had not been perpetually cold and dead, as once believed, but rather was host to a series of dramatic volcanic eruptions in which vast seas of molten lava flooded much of the lunar surface. While the majority of such activity most likely occurred very early in the Moon's history over three billion years ago, the Moon is thought to still harbor some remnant volcanic and tectonic activity. Outgassing events, in which alpha-particle emissions of radon leak out from the lunar interior, are scientific evidence of such activity. Polonium, a natural-decay product of the heavier element radon, itself a natural-decay product of the still heavier element uranium, collects around vents and provides keys to their recent history. This is due to the fact that the entire decay chain takes over 21 years, so that Polonium is evidence of vent activity over the last half century. Radon gas and polonium are likely to be detected because of their relatively long half-lives (3.8 days for [222] radon and 138 days for [210] polonium; one half-life is the amount of time it takes for half of a given radioactive sample to decay into another substance).

Ancient volcanic vents, seismic fractures, impacts and pore openings in the lunar soil all provide paths for radon to find its way to the lunar surface. Actually, radon itself is present in very small quantities, but thought to be mixed in with other gases, such as nitrogen, carbon monoxide and carbon dioxide. Determining where and when such gas-release events take place can tell scientists just how active the Moon actually is, as well as help to identify the source(s) of the Moon's small and tenuous atmosphere.

An alpha particle is the nucleus of a helium atom: two protons and two neutrons bound together. Like gamma rays, alpha particles escape from radioactive elements as part of their natural-decay process. The alpha particles are emitted with a precise energy that serves as a fingerprint for the atom from which they came. Lunar Prospector's Alpha-Particle Spectrometer (APS) detects these events.

Housed inside the APS instrument are ten separate wafers of silicon. Silicon is a semiconductive material. When an alpha particle hits a silicon wafer, it creates a small track of charge. When a 25-

volt bias is applied to the silicon wafer, the alpha particle's charge is funneled into an amplifier which then increases the charge. Since that pulse of charge is directly proportional to the signature energy of the alpha particle, scientists can infer the identity of the element which emitted the alpha particle. The APS contains ten such silicon detectors, each sandwiched between gold and aluminum disks, and arranged on five out of six sides of a cube, enabling nearly a complete field of detection.

The detection of gases depends very much on whether any outgassing events occur while Lunar Prospector is in orbit and near by the event, and how many of these there are. As with the GRS, the longer the mission lasts, the more of these events the instrument is likely to detect. Because the outgassing events are localized and may have limited duration, the longer the detection time, the greater the opportunities to detect specific events.

Before Lunar Prospector

Apollo 15 and 16 scientists, using an APS instrument for the first time, found evidence for a spatially variable distribution of radon and polonium. Those studies identified a striking correlation between polonium and the edges of lunar maria, especially Mare Fecunditatus, but also at nearly all maria investigated.

Earlier astronomical studies noted that the Aristarchus crater region was the site of phenomena dubbed "transient optical events," in which regions of the lunar surface glowed and changed color for short periods of time. Some scientists believe that the light flashes may represent transient venting of volatile materials.

Factors in Analyzing APS Data

Data acquired by the APS aboard Prospector will appear in the form of counts -- very similar to the way the GRS instrument works. As with the GRS data, the number of counts accumulated (and thereby the time of sampling), are the key determinants of the sensitivity of the data. As such, the planned extended mission flown at low altitude will most likely be extremely valuable. If the extended mission lasts for 6 months as currently planned, this will provide mission scientists with 18 months' worth of mapping time, covering the entire Moon many times over. For comparison, the Apollo 15 and 16 missions gathered only about 8 days' worth of data around the Moon's equator.

One issue mission planners have to take into account when designing alpha-particle spectroscopic experiments (and in fact any type of experiment in which a spectrometer measures cosmic radiation) is the timing of the solar cycle. Repeating every 11 years, the solar cycle is a periodic phenomenon in which the overall extent of radiation (in the form of solar particles called protons and alpha particles) produced by the Sun varies in a predictable manner. A new solar cycle began in 1997, at which time sunspot activity was at a minimum and galactic cosmic rays (GCR) were at their 11-year maximum. Since more GCR protons imply more induced planetary gamma-ray emission, the present time is optimal for performing global spectrographic mapping experiments, such as gamma-ray and neutron spectroscopy, because the inherent signal to be detected will be higher than usual. However, as we get closer to solar maximum, solar activity and its associated solar energetic-particle population will increase, leading to higher background radiation "noise", so mission scientists must take into account such stray counts and subtract them from the overall data.

NEUTRON SPECTROSCOPY

Lunar Prospector mission scientists devised the neutron spectroscopy experiment to search for water ice at the poles of the Moon. As the world found out on March 5, 1998, at the mission's first science data return press conference, preliminary results from the experiment were indeed positive: water ice does exist on the Moon, and there appears to be more of it at the North than at the South pole. Lunar Prospector had detected a significant amount of hydrogen which is inferred to be in the form of water. This was the first direct evidence of the presence of water ice at the Moon's frigid poles. Lunar Prospector is also the first interplanetary mission ever to use the neutron spectroscopy technique to detect water. Prospector's neutron spectrometer (NS) works by detecting hydrogen, by way of subatomic particles called neutrons.

Neutron Science

The materials we use every day are made up of molecules, which are made up of atoms. Inside the atoms are even tinier pieces of matter called subatomic particles. Neutrons are one type of subatomic particle -- they are present in every atom of every molecule in our bodies as well as in all of the synthetic and natural substances in our environment. Besides being a basic building block of matter, neutrons serve as a useful experimental tool for physicists. Materials scientists, for instance, are interested in how atoms are packed within the molecules of different materials. How the individual atoms of a given material stack up against each other in large part determines the properties (strength, plasticity, etc.) of that particular material. One way scientists study molecular structure is to bombard atoms with high-energy neutrons and then wait and see where and how fast the neutrons scatter.

The same thing happens naturally in space. When cosmic rays collide with atoms in the lunar crust, they violently dislodge neutrons and other subatomic particles. Some of the neutrons escape directly into space -- essentially unchanged -- as "fast" neutrons. Other neutrons shoot off into the crust, where they slam into other atoms, bouncing around like pinballs. If they only run into heavy atoms, they do not lose very much energy in the collisions, and are still traveling at close to their original speed when they finally bounce off into outer space. But if a neutron encounters a hydrogen atom -- which is the same size as a neutron -- it will slow greatly or even stop, much like a speeding billiard ball running into a stationary one. If the Moon's crust contains an abundance of hydrogen at a certain location -- say, a crater with water ice in it -- any neutron that bounces around in the crust before heading out to space will cool off (slow down) rapidly. When Lunar Prospector flies over such a crater, the NS will detect a definitive dropoff in the number of these ("epithermal" or medium energy) neutrons.

How Lunar Prospector's NS Works

The NS has two different counters -- a cadmium-wrapped canister of [3]helium and a tin-wrapped canister of [3]helium. When a neutron collides with an atom of [3]helium, a nuclear reaction takes place, producing a burst of energy. That burst of energy tells mission scientists that they have detected a neutron. Except for the outside wrapping, the two counters are nearly identical. The cadmium-wrapped counter filters out all but the epithermal neutrons, because cadmium is good at screening away the slow-moving thermal neutrons, whereas the tin-wrapped counter lets all of the neutrons through. Since the two counters are otherwise identical, counts can be subtracted, and any difference between the two must be attributable to thermal neutrons.

Lunar Prospector measures “fast” and thermal plus epithermal neutron flux with a separate instrument (the anti-coincidence shield of the GRS). The respective count rates of the different types of neutron fluxes are an indicator of hydrogen, and hence the presence of water ice, embedded within the lunar soil.

Mission scientists receive data from the spacecraft every 32 seconds. Since the data contain random noise, several passes over the surface and careful statistical analysis are required to analyze the data. However, since the spacecraft passes over the poles every orbit (whereas it passes over any given region on the equator only a few times a month), the NS produces the most accurate data in the polar regions.

MAGNETOMETER/ELECTRON REFLECTOMETER STUDIES

The magnetometer and electron reflectometer aboard the Lunar Prospector are collecting valuable data to help unravel puzzles that have intrigued scientists for more than a quarter of a century. What kind of magnetic field(s) exists on the Moon? What kind of natural resources are buried in the Moon’s crust and is there a core? If so, what are its characteristics? Can we build a lunar base? How did the Moon form and evolve -- what is its history?

The MAG/ER experiment aboard Lunar Prospector was designed with two primary goals in mind: scanning the lunar crust for signs of permanent magnetization, and searching for electrical currents flowing deep within the lunar interior -- the sign of a conductive metallic lunar core. The two instruments combine to calibrate the Moon’s global magnetic field strength: the magnetometer measures the field surrounding the spacecraft, and the electron reflectometer surveys the lunar surface.

How Much Do We Already Know about the Moon’s Magnetic Field?

Scientists have known for years that the Earth is magnetic -- there is a strong magnetic field surrounding our own planet, originating with electrical currents swirling inside the Earth’s iron-rich metallic core. The boundary between the Earth’s magnetosphere (a dipole field) and the influence of the Sun’s charged particle activity (from the solar wind) for the most part balances out. At times, however, especially during a particularly active segment of the 11-year solar cycle when solar flares are raging, charged solar wind particles get trapped by the Earth’s magnetic field and slam into the Earth’s atmosphere at extremely high energies. As a result, the atmosphere glows, and a strange but beautiful phenomenon called the Aurora Borealis is formed. Such events are most prominent at the Earth’s poles; hence, Alaska is an oft-cited viewing spot for such celestial fireworks.

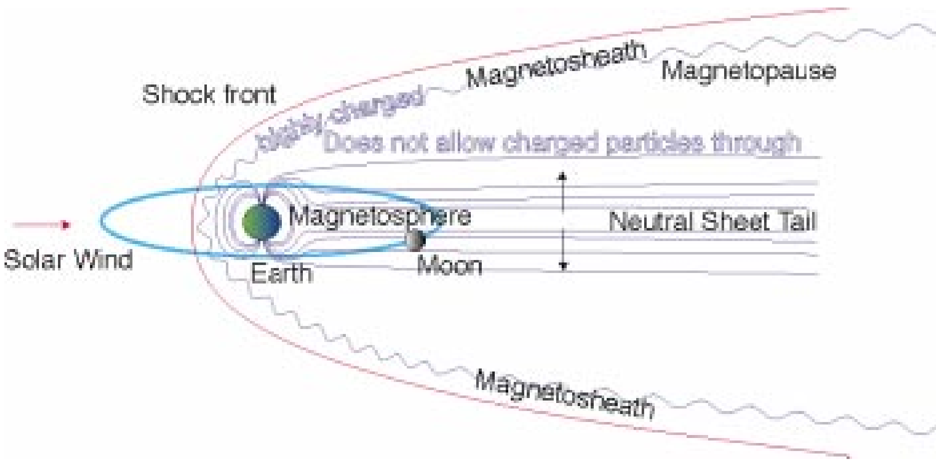


Illustration showing the Earth's magnetosheath and the shock front it creates

The Moon is a different story. Based upon previous, albeit limited research, scientists have suspected that the Moon has very little, if any, magnetic field of its own. The first spacecraft to effectively measure lunar magnetic fields was Explorer 35, several years prior to Apollo. The Apollo 15 and 16 subsatellites orbited the Moon with magnetometer instruments and concluded that the Moon possessed a vanishingly small global magnetic field; however, other experiments aboard Apollo 12, 14, 15 and 16 with either hand-held or stationary magnetometers detected small but significant surface fields. In particular, one unresolved issue facing the lunar scientific community is the origin of swirl-like color markings (called "albedos") visible from orbit on the surface of the Moon that are thought to be due to magnetic anomalies.

Why Are We Interested in the Magnetic Field?

The presence of such non-uniformly distributed magnetic regions has led planetary scientists to conjecture about the Moon's impacts (which may have imparted some of these locally distributed magnetic properties) and the possible presence of a small, iron-laden core (roughly estimated to a maximum of about 500 km in radius). From the perspective of planetary science, better understanding the size and nature of the Moon's core can tell a lot about its evolution, history and beginnings -- such as, did the Moon really arise as the result of a cataclysmic collision between the Earth and a Mars-sized body? In addition, metals discovered in the crust may be an extremely valuable resource. Now that mission scientists have found a potential source of water on the Moon, the presence (and relative abundance) of other materials may become paramount to the eventual establishment of a future possible lunar base.

How it Works

Lunar Prospector's magnetometer/electron reflectometer (MAG/ER) measurements are affected by three sources: the Earth's magnetic field (35,000 nano Teslas), the relatively weak field of the Moon (0 to 300 nano Teslas) and the very weak field carried from the Sun by the solar wind (approximately 10 nano Teslas). Mission scientists are able to compare these measurements to determine which magnetic field variations are caused by surface features (local deposits of magnetic material) or alternatively, by the Moon's core. Both instruments are copies of detectors currently housed aboard the Mars Global Surveyor spacecraft, launched in December 1996, with some modifications to adapt them for a spinning spacecraft.

The triaxial fluxgate MAG is a standard device that is also used to measure magnetic fields on Earth. "Triaxial" means that it includes sensors to measure the strength of the field in three different directions. This enables scientists to determine not only the maximum strength of the field but also the direction in which it points. The "fluxgate" is an electric coil through which the magnetic field passes. By measuring the variation of the current passing through the coil, the MAG determines the strength of the magnetic field. It can measure magnetic fields as weak as one-millionth the strength of the Earth's magnetic field.

Prospector's ER measures the magnetic field at the surface of the Moon. The Moon, like every other body in the Solar System, is constantly barraged by electrons from the solar wind. Unlike the Earth, the Moon was not thought to have a magnetic field strong enough to repel these tiny charged particles, and they would be expected to spiral toward the surface in giant loops, typically several miles wide. The electrons that descend in a tighter spiral make it to the surface of the Moon and are absorbed there. But if there is magnetic material on the Moon, it will reflect some of the electrons back into space. When those reflected electrons reach the Lunar Prospector spacecraft, the ER measures their pitch angle (the angle at which they bounce). After the pitch angles of many electrons are tabulated, scientists will see an abrupt cutoff above a certain angle -- because all the electrons with a larger pitch angle were absorbed by the Moon. That cutoff tells mission scientists just how intense the magnetic field is at the lunar surface.

Together, the two instruments detect local variations in the Moon's magnetic field that arise from selenological features on the lunar surface. Lunar Prospector's MAG instrument not only measures lunar magnetic fields, but also external fields present in space plasmas (a plasma is an electrically conductive gas comprised of both neutral and ionized particles and free electrons). As a result, only a small fraction (about 10 percent) of the MAG's data is pertinent to lunar scientists. What that means is that culling relevant data poses a significant challenge for Prospector's MAG/ER team. Essentially, this involves careful pruning of the data as well as paying attention to what times of the month the data has been gathered, as certain times (and thereby location relative to the Earth and its own magnetic field) are better than others for measuring lunar fields.

The interaction between charged particles in the solar wind and the Earth's magnetic field (about 220 miles above the surface of the Earth) is a region scientists call the magnetosphere. Within the magnetosphere are two separate regions: the magnetosheath (which is magnetically "noisy") and the geomagnetic tail (which, by comparison, is "quiet"). It is important that mission scientists take lunar magnetic measurements while the spacecraft passes through the quieter geomagnetic tail. The data will be expressed in units called "gammas" (which are the same as nano Teslas, or one-billionth of a Tesla) and will be tagged with spacecraft positional data to produce computer files which demonstrate magnetic field components as a function of location relative to the Moon as well as spacecraft altitude.

As is the case with all of Prospector's scientific experiments, the spacecraft's polar orbiting pattern permits complete global analysis of the Moon. So, for the first time, scientists can have a handle on all of the Moon's magnetic features, not just those associated with isolated geologic regions. Such analyses also permits scientists to correlate magnetic properties with lunar surface features -- the MAG data is an essential component in analyzing the data from the ER instrument. Data from the ER will be plotted as electron flux (number of particles per unit area per unit time) as a function of time. The ER "probes" (from orbit, of course) the lunar surface by recording the behavior of space-born electrons after they bounce off of the lunar crust. But while the ER is capable of measuring the strength of electron paths ("bent" by tiny, locally dispersed lunar magnetic fields), this instrument is incapable of determining where on the Moon it is measuring electrons at any given time. Positional data from the MAG puts the ER data into perspective, allowing mission scientists to match up electron flux strengths with the magnetic fields along which they travel. Thus, the two instruments (which are housed together on one of Prospector's eight-foot booms) cooperate to provide mission scientists with a complete picture of the Moon's magnetic and electrical properties. All told, it will take mission scientists the full year of mapping to acquire meaningful data about the magnetic fields of the Moon.

GRAVITY STUDIES

The gravity field of the Moon strongly influences the altitude of a spacecraft in low-circular orbit. The most dramatic example is the Apollo 16 subsatellite. After being deployed in a near-circular orbit from the command and service module, the eccentricity increased quickly and the spacecraft impacted the lunar surface 35 days after the release strictly due to the force of the gravity field. Understanding the precise nature of a planet's gravity field is vital to all exploration and experimentation.

As presented at the March 5 science return press conference, Lunar Prospector's Doppler Gravity Experiment (DGE) has provided the first polar low-altitude measurement of the lunar gravity field. This provided the spacecraft with the first truly operational gravity map of the Moon and immediately improved orbit and fuel efficiency. Improved gravity information will not only help scientists build better models of the role of impact processes on the history and evolution of the Moon, but will also help in estimating the lunar core size and metallic iron content. A more practical benefit of the new lunar gravity data provided by Prospector's DGE experiment is that a more precise gravity map of the Moon will inevitably aid future mission planners in planning fuel-efficient journeys to the Moon, and may even help identify potential resources.

Lunar Prospector's Doppler Gravity Experiment

The Moon has a large asymmetry due to the fact that the lunar crust is thicker on the far side than on the near side and a much "bumpier" gravitational field than the Earth, with small anomalies due to mass concentrations on the surface. The Apollo missions helped demonstrate such sizable positive gravity anomalies. Interestingly, they exist within the topographically low, large circular mare basins. This discovery was unexpected and opposite of any physical model at that time and started the development of new models of the Moon's interior. The features were called mascons (short for "mass concentrations"). These bumps cause an orbiting spacecraft to speed up or slow down. The DGE is, in effect, drawing a map of the bumps.

The DGE, unlike the other experiments aboard Lunar Prospector, requires no extra instrumentation. All of the data is collected simply by communicating with the spacecraft. As the spacecraft orbits the Moon, its speed can always be determined by the Doppler effect, the same effect that causes a police siren to sound higher when the police car is moving toward you and lower when it is moving away from you. The "siren," in this case, is the spacecraft's radio signal, whose frequency shifts slightly as it moves toward Earth or away from it. Relative to the near side, lunar farside gravity is poorly determined because the spacecraft is not in view from the Earth when over the lunar far side. However, some information is obtained by observing changes in the LP orbit due to the accumulated acceleration of the farside gravity as the spacecraft comes out of occultation (back into view).

By tracking the velocity of the spacecraft, mission scientists can infer the forces acting upon it. For over 99 percent of the duration of the mission (excepting only periods when the engines are being fired) the only force on Lunar Prospector is gravity. Thus, by simply circling the Moon and sending signals back to Earth, Lunar Prospector has mapped the Moon's global gravitational field. Lunar Prospector completed this gravitational map in the first two months of the mission. However, the results of the DGE will be greatly improved with data from the extended, low-altitude phase of the mission. At this low altitude of 6 miles (10 km), the precision of the gravity data will be improved by a factor of over 100.

SCIENTISTS' BIOGRAPHIES

Dr. Mario Acuña (Goddard Space Flight Center, Greenbelt, MD)

Dr. Mario Acuña is a Co-Investigator for the Lunar Prospector mission, responsible (along with Dr. Lon Hood) for the spacecraft's Magnetometer instrument. Dr. Acuña was born in 1940, in Cordoba, Argentina, from where he later received his undergraduate degree at the University there. He went on to receive an MSEE degree in 1967, from the University of Tucuman and then a doctorate in space science from the Catholic University of America, in Washington, D.C., in 1974. From 1963 to 1967, Dr. Acuña worked for the department of electrical engineering and the Ionospheric Research Laboratory at the University of Tucuman, as well as for the Argentine National Space Research Commission. These research activities included several cooperative sounding rocket programs with NASA's Goddard Space Flight Center involving both U.S. and South American scientists, X-ray research with high-altitude balloons and meteorological tracking stations. In 1967, he joined the Fairchild-Hiller Corporation in Germantown, Maryland, to provide engineering and scientific support services to NASA; he became head of the Electronic Systems Division in 1968. Since 1969, Dr. Acuña has been associated with NASA's Goddard Space Flight Center in Greenbelt, Maryland, where his research interests have centered around experimental investigations of the magnetic fields and plasmas in the Solar System. He has participated in several planetary missions, including the Explorers 47 and 50 missions, Mariner 10, Pioneer 11, Voyagers 1 and 2, MAGSAT, Project Firewheel (Germany, Canada, United States and United Kingdom), Viking (Sweden), the Active Magnetospheric Particle Tracer Explorers (AMPTE: Germany, United States, United Kingdom), The International Solar Polar Mission and the GIOTTO mission (ESA) to comet Halley. In 1986, he was selected as the Principal Investigator for the Mars Observer Magnetic Field Investigation (launched in 1992) and is currently in charge of the Mars Global Surveyor spacecraft's magnetometer. Dr. Acuña has published more than 60 research articles, mainly in the field of planetary magnetism.

Dr. Alan Binder (Lunar Research Institute, Gilroy, CA)

Dr. Alan Binder is Principal Investigator and flight director for the Lunar Prospector mission. Dr. Binder earned a bachelor's degree in physics in 1961 from Northern Illinois University, and in 1967, earned a doctorate in geology and lunar and planetary science from the University of Arizona's Lunar and Planetary Laboratory. His main research interests center around the origin, petrological and structural evolution of the Moon, as well as its possible economic utilization. Dr. Binder has 35 years of experience in the fields of planetary astronomy and planetary geosciences. He was a Principal Investigator on the 1976 Viking Mars Lander Camera Team. For 10 years, he both taught and conducted lunar research in Germany and served as an advisor to the European Space Agency in its studies of a lunar polar orbiter mission. While in Germany, Dr. Binder also developed the proposed German and American lunar exploration program, "Selene," which was to be a series of lunar landers used to set up a geophysical station network and return samples to Earth. Selene was the forerunner to NASA's proposed Common Lunar Lander (Artemis), a project on which Dr. Binder also worked. He has authored or coauthored some 60 scientific papers, mainly in the areas of lunar and Mars geology, geochemistry, petrology and geophysics.

Mr. David Curtis (Space Sciences Laboratory, Berkeley, CA)

David Curtis has an M.S. in Electrical Engineering and an M.A. in Physics and has worked as an Electrical Engineer at the University of California, Berkeley, Space Sciences Laboratory for over 15 years. His experience includes Instrument Project Manager for the Wind 3DP instrument and the Mars Observer, Mars Global Surveyor, and Lunar Prospector Electron Reflectometer instruments; Lead Engineer for the digital/processor electronics for the AMPTE IRM plasma instrument, the Cluster CIS instrument, the Giotto RPA PAD system, and the FAST Instrument Data Processing Unit (IDPU) digital system. He designed and implemented the FAST Mission Operations Center/Science Operations Center and also designed the FAST IDPU.

Dr. William Feldman (Los Alamos National Laboratory, Los Alamos, NM)

Dr. William Feldman is a Co-Investigator for the Lunar Prospector mission and serves as the Spectrometer Group Leader, overseeing the operation of three of the spacecraft's instruments: the neutron spectrometer, gamma ray spectrometer and alpha particle spectrometer. Dr. Feldman was born in 1940. He received a bachelor's degree in physics from the Massachusetts Institute of Technology in 1961 and later earned a doctorate in nuclear structure from Stanford University, in 1968. He has 17 years of experience in analyzing and interpreting solar wind and magnetospheric data. He has participated in the design of seven plasma experiments and an energetic electron dosimeter. Dr. Feldman was the Principal Investigator on a total-absorption neutron spectrometer rocket experiment and a fast neutron spectrometer launched aboard the Naval Research Laboratory LAEC spacecraft. He was also a Co-Investigator on a variety of missions, including Pioneer 10 and 11, IMP 6, 7 and 8, ISEE 1,2 and 3, Mariner 10, Giotto JPA and the Ulysses Space Plasma Physics Experiments. Dr. Feldman was also a member of the Mars Observer Gamma Ray Spectrometer Team, with responsibility for the neutron sensor/charged particle anti-coincidence shield and is chairman of the Solar Probe Science Study Team. He has authored or co-authored more than 180 scientific papers.

Dr. Lon Hood (University of Arizona, Tucson, AZ)

Dr. Lon Hood is a Co-Investigator for the Lunar Prospector mission, responsible (along with Dr. Mario Acuña) for the spacecraft's Magnetometer instrument. Dr. Hood was born in Marshall, Texas in 1949, and received a bachelor's degree in physics in 1971 from Northeast Louisiana University. He later earned a doctorate in geophysics and space physics from the University of California, Los Angeles, where he studied mapping and interpretation of lunar crustal magnetic anomalies using the Apollo 15 and 16 subsatellite magnetometers. Dr. Hood is presently a staff member of the Lunar and Planetary Laboratory at the University of Arizona, where his research for the past several years has focused on theoretical and observational studies of lunar magnetism, outer planet magnetospheres and the terrestrial middle atmosphere. He has served on a number of NASA committees on the Moon and asteroids and has authored or co-authored some 60 scientific papers and two book chapters.

Mr. G. Scott Hubbard (NASA Ames Research Center, Moffett Field, CA)

Mr. Scott Hubbard is NASA mission manager for Lunar Prospector and also a Co-Investigator, responsible for the spacecraft's Gamma Ray Spectrometer instrument. Mr. Hubbard received a bachelor's degree in physics from Vanderbilt University in 1970 and has done graduate work at the University of California, Berkeley. He is the originator of the Mars Pathfinder (formerly MESUR) mission. He is currently Deputy Director of Space at NASA

Ames Research Center, where he supervises studies, hardware development and mission operations on such missions as Pioneer and the Galileo Probe. Mr. Hubbard has also contributed experimental hardware to numerous ionizing radiation investigations, including balloon experiments, Apollo-Soyuz and HEAO-Cand ISEE-3. While at Lawrence Berkeley Laboratory, he developed the first thin-window germanium charged-particle telescope, as well as basic technology for ultra-pure germanium gamma ray devices and for far infrared photoconductors. Before coming to Ames, Mr. Hubbard was General Manager for Canberra Semiconductor, and a Senior Research Physicist at SRI International. He has received numerous honors, including NASA's Exceptional Achievement Medal and is the author of more than 30 papers on radiation detection and space missions.

Dr. Alexander Konopliv (Jet Propulsion Laboratory, Pasadena, CA)

Dr. Alexander Konopliv is a Co-Investigator for the Lunar Prospector mission, responsible for the Doppler Gravity Experiment, which will use the spacecraft's telemetry data to measure the Moon's gravitational fields. Dr. Konopliv was born in Minneapolis, Minnesota in 1960 and received a bachelor's degree in aerospace engineering and mechanics from the University of Minnesota in 1982. In that same year, he received a master's degree in aerospace engineering from the Massachusetts Institute of Technology, and in 1986, he earned a doctorate in aerospace engineering from the University of Texas at Austin. Dr. Konopliv has been involved in planetary gravity analysis since 1991 as a member of the Planetary Gravity Analysis Group in the Navigation Systems Section of the Jet Propulsion Laboratory. Currently, he is processing the Magellan Doppler tracking data and combining it with the Pioneer Venus Orbiter tracking data to produce a 75th degree and order spherical harmonic gravity field model. This high resolution gravity field model will be made available to the Magellan science team for geophysical investigation. Dr. Konopliv's work on the lunar gravity field from the reduction of Apollo and Lunar Orbiter data provides the basis for determining the lunar orbit maintenance requirements for Lunar Prospector. This gravity field model was also used by the Clementine mission during operations for real-time orbit determination of the spacecraft. Dr. Konopliv has authored or co-authored a dozen papers on planetary gravity fields and celestial mechanics.

Dr. David J. Lawrence (Los Alamos National Laboratory, Los Alamos, NM)

Dr. David Lawrence is a Post-Doctoral Research Associate on the Space Physics Team in Space and Atmospheric Sciences at Los Alamos National Laboratory. As a member of the Lunar Prospector Spectrometer Team, he has carried out much of the initial analysis for the LP gamma-ray spectrometers and neutron spectrometers. He received his B.Sc. in physics and mathematics from Texas Christian University in 1990, followed by his M.A. in physics from Washington University, St. Louis in 1992 and his Ph.D. in physics from Washington University, St. Louis in 1996. Since arriving at Los Alamos, Dr. Lawrence has contributed to a variety of space physics and planetary science projects. These include preparing data analysis code and carrying out data analysis for the Lunar Prospector mission. He has also assisted in the construction, testing, and calibration of the Plasma Experiment for Planetary Exploration (PEPE) instrument for the NASA New Millennium program. He has also conducted magnetospheric studies using data from the LANL Magnetospheric Plasma Analyzer instruments. Prior to his work at Los Alamos, he designed, tested, flew, and analyzed data for a high-altitude balloon experiment designed to measure the elemental abundances of the galactic cosmic rays heavier than iron. He is a member of the American Geophysical Union, the American Physical Society, and a full member of Sigma Xi. Dr. Lawrence has authored or co-authored over a dozen papers on balloon and spacecraft instrumentation along with topics of space and planetary science.

Dr. Robert Lin (University of California, Berkeley, CA)

Dr. Robert Lin is a Co-Investigator for the Lunar Prospector mission, responsible for the spacecraft's Electron Reflectometer instrument. Dr. Lin was born in Kwangsi, China in 1942 and later became a U.S. citizen. He received a bachelor's degree in physics from Cal Tech in 1962 and earned a doctorate in physics from the University of California, Berkeley, in 1967. He is currently Professor of Physics and Associate Director of the Space Sciences Laboratory at U.C. Berkeley. Dr. Lin has developed experiments for numerous missions, including lunar orbiting Explorer 35 and the Apollo 15 and 16 subsatellites. Dr. Lin and his colleagues developed the electron reflectometer technique for remotely measuring surface magnetic fields on planetary bodies. He is the Principal Investigator for the plasma and energetic particle experiment on the Wind spacecraft, lead Co-Investigator for the Electron Reflectometer experiments on the Mars Observer and Mars Global Surveyor spacecraft, and Principal Investigator for hard X-ray and gamma ray spectrometer experiments for astrophysics and solar physics from balloons. He is also a Co-Investigator on Ulysses, ISTP Cluster and Equator spacecraft experiments. Dr. Lin has authored or co-authored 236 papers on solar, interplanetary, planetary, magnetospheric physics and astrophysics.

Dr. Sylvestre Maurice (Observatoire Midi-Pyrenees, Toulouse, France)

Dr. Maurice is an astronomer on the planetology team of the Laboratory of Astrophysics in Toulouse. As a member of the Lunar Prospector Spectrometer Team, he has carried out much of the initial analysis for the LP neutron spectrometer. He received his B.Sc. in aeronautics and space engineeing from ``Sup-Aero", Toulouse, in 1990, followed by his M.S. in astrophysics from Toulouse University, the same year, and his Ph.D. in astrophysics from Toulouse University in 1994. He was then a post-doc for 2 years at the European Space Agency in the Netherlands, and a post-doc for 16 months at the Los Alamos National Laboratory in New Mexico. In 1998, Dr. Maurice was awarded a permanent position at the Observatoire Midi-Pyrenees in Toulouse, France. Since his graduation, Dr. Maurice has contributed to a variety of space physics and planetary science projects. These include modeling the magnetosphere of Saturn in preparation to the CASSINI mission and understanding the complex interaction of the Shoemaker-Levy 9 comet with Jupiter's magnetosphere. He has also conducted magnetospheric studies around the Earth using data from geosynchronous satellites. For these topics, Dr. Maurice has authored or co-authored over 15 refereed papers.

GLOSSARY

gamma ray — a type of high-energy radiation

highlands — heavily cratered light-colored regions of the lunar surface (the Moon's oldest rocks)

KREEP — an elemental composite material (used by scientists as a chemical tracer) consisting of K-potassium, Rare Earth Elements, and P-Phosphorous

Lunar eclipse — period in which the Earth is positioned so as to obscure the Moon from sunlight

maria — smooth, dark regions of the lunar surface (the Moon's youngest rocks)

mascon — concentrations of mass on the lunar surface

outgassing — venting of gases from the lunar interior

regolith — a mixture of fine dust and rocky debris (produced by meteor impacts) covering the lunar surface

selenology — scientific study of the history of the Moon, as recorded in rocks