LUNAR PROSPECTOR

End of Mission &
Overview

Press Kit

July, 1999

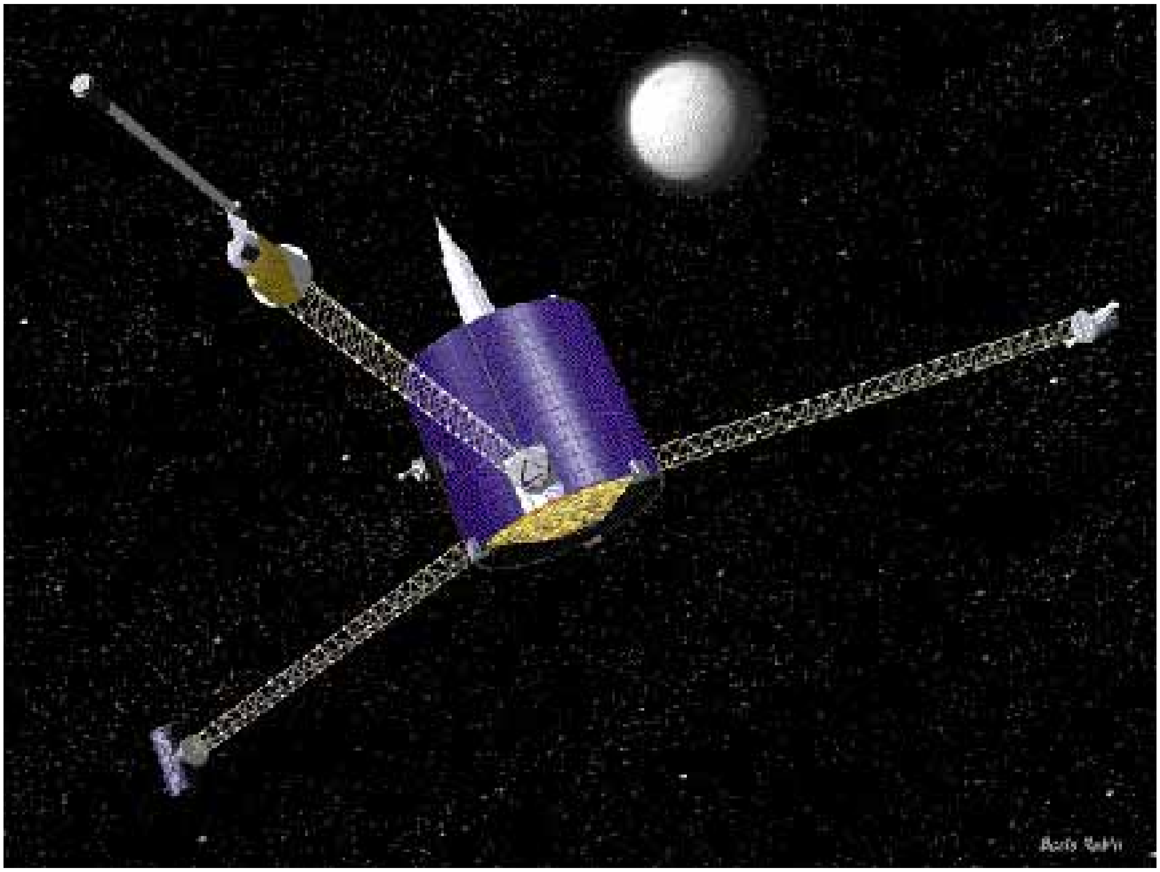

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TABLE OF CONTENTS

Introduction

Lunar Prospector, the first dedicated lunar mission in 25 years, will complete a highly successful mission life with a spectacular high-speed, south polar impact on 2:51 am July 31st, 1999 (PDT).

In a bold stab at gleaning ever more high quality science from one of the most cost effective missions ever flown, the tiny spin-stabilized spacecraft will be commanded into a highly elliptical orbit and purposefully crashed into a permanently shadowed crater that is likely to contain cometary ice. If all goes well and the spacecraft clears the rim of the ~ 50 km. wide crater, impacts the crater edge in an area of such complete darkness that there is only scanty data for the region, and succeeds in hitting an ice deposit, a vapor cloud should be visible from one of the ground and space based telescope facilities that will be trained on the event. The McDonald Observatory, Hawaii's Keck Telescope, the Submillimeter Wave Satellite (SWAS), and Hubble Space Telescope (HST) will be just a few of the facilities eagerly fixed on the south pole of the Moon in this low-probability, high pay-off attempt to get a direct signal of the water ice deposits inferred from early LP data.

Following a near flawless launch on Jan 6, 1998, a four-day journey to the Moon and entry into lunar orbit, Lunar Prospector has been sending data back to Earth from its circular polar mapping orbit since January 15, 1998. The spacecraft's suite of 5 science instruments and 6 experiments was designed to provide global data on key characteristics of the Moon: elemental abundances, gravity fields, magnetic fields and outgassing events. This information was intended to completely map the Moon and complement existing data, largely from the Apollo era, that concentrated on the equatorial regions. It would improve our understanding of the origin and evolution of the Moon and increase our knowledge of the Moon in general. Prospector has accomplished all that and more.

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. Neutron Spectrometer (NS) data published in the September 4th issue of *Science* indicated that further analysis of the data had shown that the suspected water ice appeared to be in discreet deposits buried under lunar soil, rather than the scattered ice crystals first hypothesized.* The first competitively selected Discovery class mission had conclusively demonstrated that, not only could a cost-capped, fast-development mission succeed, it could do groundbreaking science in the process.

January of 1999 marked the beginning of Prospector's extended mission: a riskier six months of mapping at a low 30 km orbit that would greatly enhance the resolution of several experiments, including the NS experiment. Extended mission mode, which has brought the spacecraft as close as 10 km to the surface of the Moon, has indeed increased resolution and enhanced the quality of Prospector's science data. The lunar community now has available a complete, high quality gravity map of the Moon, global magnetic field maps, global absolute abundances of 11 key elements, including hydrogen, and finally, a slim but, significant chance to glean a direct measurement of water ice from the last moments of a truly, faster, better, cheaper space mission.

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* The most recent results,based on extended mission, low altitude mapping are discussed under Neutron Spectrometer Experiment Results.

Primary/Extended Mission Overview, Objectives & Goals

Spacecraft Description & Primary Mission

Lunar Prospector’s primary mission was a one year circular, polar mapping of key characteristics of the Moon, including elemental abundances, gravity fields, magnetic fields, and outgassing events. The spacecraft was equipped with an instrument (Neutron Spectrometer) capable of directly detecting hydrogen which could indicate water ice. The spacecraft itself is a small, simple, spin-stabilized orbiter. It consists of a graphite/epoxy bus, 1.3m diameter X 1.4m tall with three 2.5 meter science masts for deploying its five science instruments. The simple spacecraft with a fully fueled mass at launch of 296.4 kg, was designed with no computer beyond a simple command and data handling unit. Prospector has been tracked by the Deep Space Network and data has been collected 24 hours a day by a small operations team working from Mission Command and Control at Ames Research Center. Lunar Prospector’s first year was spent in a 100 km circular polar orbit. Launched from Spaceport Florida’s pad 46 at Cape Canaveral on January 6th, 1998, aboard an Athena II rocket, LP took just 105 hours to reach the Moon. No camera was placed aboard the craft, as the existing lunar science database already included an impressive store of high resolution visual images, many of which were taken by the joint NASA/Department of Defense spacecraft Clementine in 1994. The spacecraft, designed and built by Lockheed Martin Missiles and Space (LMMS) Sunnyvale facility, was developed in under 22 months for a total budget of $63 M, including the launch vehicle.

All these aspects of mission design helped ensure that the Lunar Prospector would be simple, cost-effective, reliable and a model for the new way of doing business that was the Discovery program. Prospector’s first year in space was an overwhelming success by all accounts.

Science Objectives

The small spin-stabilized spacecraft had a set of mission goals which derived in part from the post-Apollo Lunar Exploration Working Group (LExWG), and in part from the new imperative within NASA to find new, cost effective means of exploring the solar system and sharing that knowledge with the public. These goals were:

Lunar Prospector's identified critical science objectives were:

- "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 instrument suite to accomplish these goals involved 5 science instruments and 6 experiments. They were:

- *Neutron Spectrometer*(NS*)* to detect hydrogen and determine if water ice deposits exist in the polar regions of the Moon.
- *Gamma Ray Spectrometer* (GRS) to map elemental composition of the lunar surface,

providing information on the composition of the surface layer and shedding light on the Moon’s origin and evolution.

- *Alpha Particle Spectrometer* (APS) to detect outgassing events to determine their frequency and location.
- *Magnetometer and Electron Reflectometer* (Mag/ER) to map lunar magnetic fields and provide information on the size and characteristics of the Moon’s inner core.
- *Doppler Gravity Experiment* (DGE) to map the global lunar gravity field and to provide an operational resource for Prospector and missions to come.

Programmatic Goals

As a Discovery mission, Lunar Prospector had programmatic goals in addition to its science goals:

- Create a new way of doing business between a government agency and the private sector .
- Demonstrate that the philosophy of "faster, better, cheaper (FBC)" can successfully yield a rapid development, very inexpensive planetary science mission with significant responsibility vested with the Principle Investigator.
- Create an innovative education and outreach program which stimulates public interest in planetary exploration.

Management - A New Way of Doing Business

In order to develop and operate a NASA mission within a tightly constrained budget, while keeping mission success as the highest priority, a number of strategies and new management tools were developed and implemented. These included maintaining a lean management structure where the key responsibilities were clearly defined and where continuous, open communications were routine. The simple spacecraft and mission design was maintained, allowing the project to avoid the typical issues that result from pressures to redefine objectives or increase payload during development. No prudent project steps were skipped during design, integration or test. The Lunar Prospector Mission Office (LPMO) with the Principal Investigator maintained a delicate balance of technical insight and programmatic oversight, avoiding "micromanagement", but keeping mission success the priority. Responsibility was vested in the developer through a single prime contract. Frequent management meetings between LPMO, the Principal Investigator, and LMMS team reduced both lost time, marching army costs and paperwork. A small, flexible core team able to handle a variety of tasks within a given discipline and willing to work through all phases, design, development, integration and test allowed an extremely efficient use of resources.

Faster, Better, Cheaper

Lunar Prospector was successfully launched on time within budget. Within three months of launch the mission had begun to return valuable science data and was clearly accomplishing its goals. A list of LP’s accomplished firsts indicates the success with which the mission demonstrates the "Faster, Better, Cheaper" concept. They include:

- 1st Competitively selected Discovery Mission
- 1st Launch of the Athena II
- 1st NASA launch from new Spaceport Florida Pad 46
- Lowest altitude mapping of another world
- 1st Operational Lunar Gravity Map
- 1st Neutron Spectroscopy for Planetary Science
- 1st Direct Measurement of Water Ice at Lunar Poles
- One of most cost effective planetary missions ever flown

Education/Outreach

The showpiece of Prospector's outreach program has been the award winning web site at:

http://lunar.arc.nasa.gov

Some highlights include: a data visualization section which allows the public to follow the instruments, spacecraft, and science data in real time; a fully detailed lunar atlas (the best currently available anywhere), extensive interactive web movies which demonstrate basic aspects of lunar science, as well as how LP's instruments work; the most extensive archive of lunar images, full length movies, video clips, and much more.

To supplement the web site a CD-Rom was produced which includes an "LP Simulation"- an interactive computer game- which focuses on mission basics such as power and communication, in an entertaining format. Another unique educational element has been LP's relationship with a private, for-profit educational group, *Space Explorers* with their Lunar Prospector based program *Moonlink*. In addition, LP reached an educational group often overlooked in space science: Kindergarten through fourth grade. The mission office developed a fun and informative paper model that uses marshmallows and soda straws to engage the very young. This innovative product has been published and utilized by numerous educational groups, including the National Science Teacher's Association.

Extended Mission

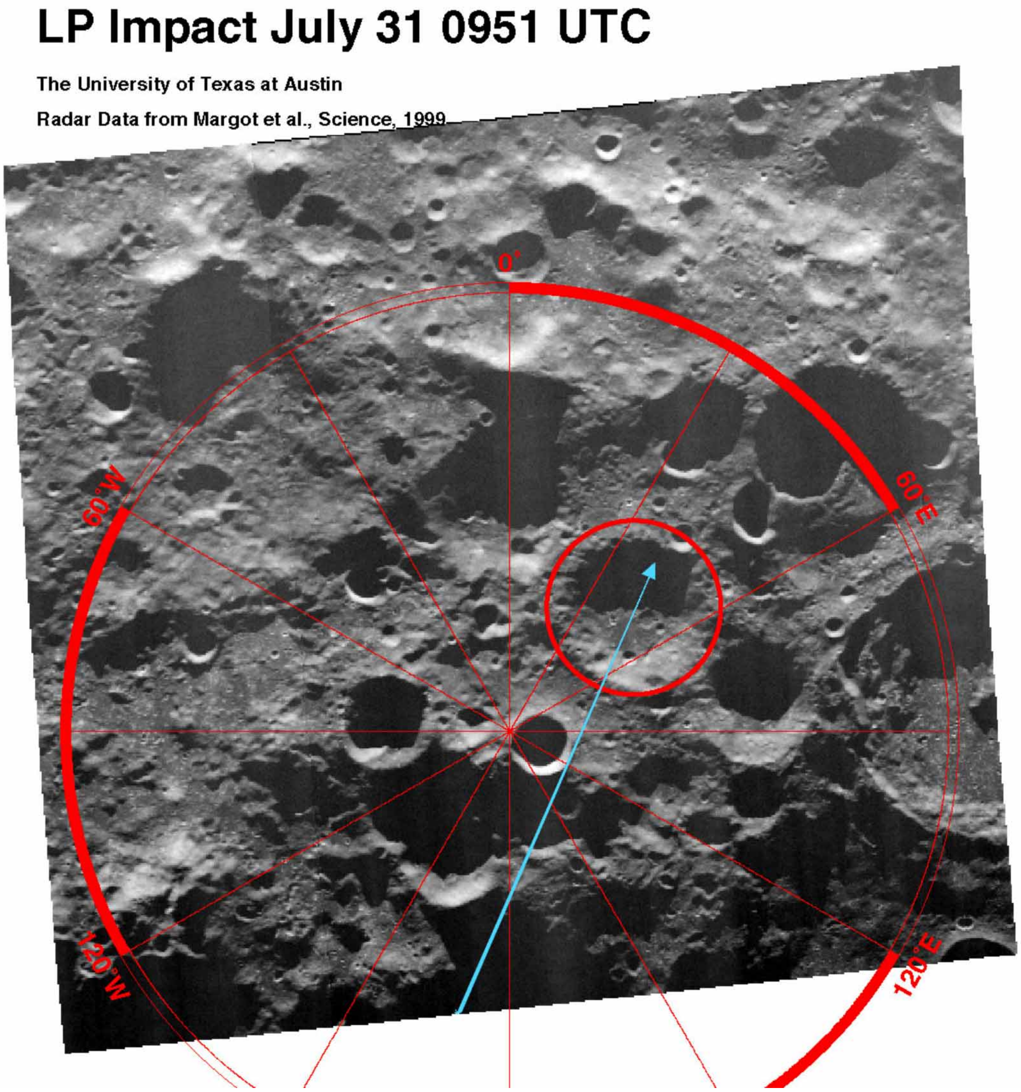
From its initial 100 km orbit above the Moon during the first year of operations, Lunar Prospector has been subsequently commanded to lower and lower orbits in order to gather ever higher resolution scientific data on the composition, evolution, and origin of the moon. During its most recent 6 months of extended mission operations, Lunar Prospector has been operating out of a 30 km mean altitude orbit, which over a course of a month, drops as low as 10 km above menacing lunar peaks and comes within only a few days of impacting the moon. In a precarious balancing act, mission controllers have used newly derived lunar gravity maps from LP's Doppler Gravity Experiment to perform monthly orbit adjustments needed to counteract the uneven gravity field of the Moon which degrades the orbit dramatically over time.

This extended mission period has increased resolution in several of LP's experiments, notably the magnetic fields experiments and the gravity fields experiments.

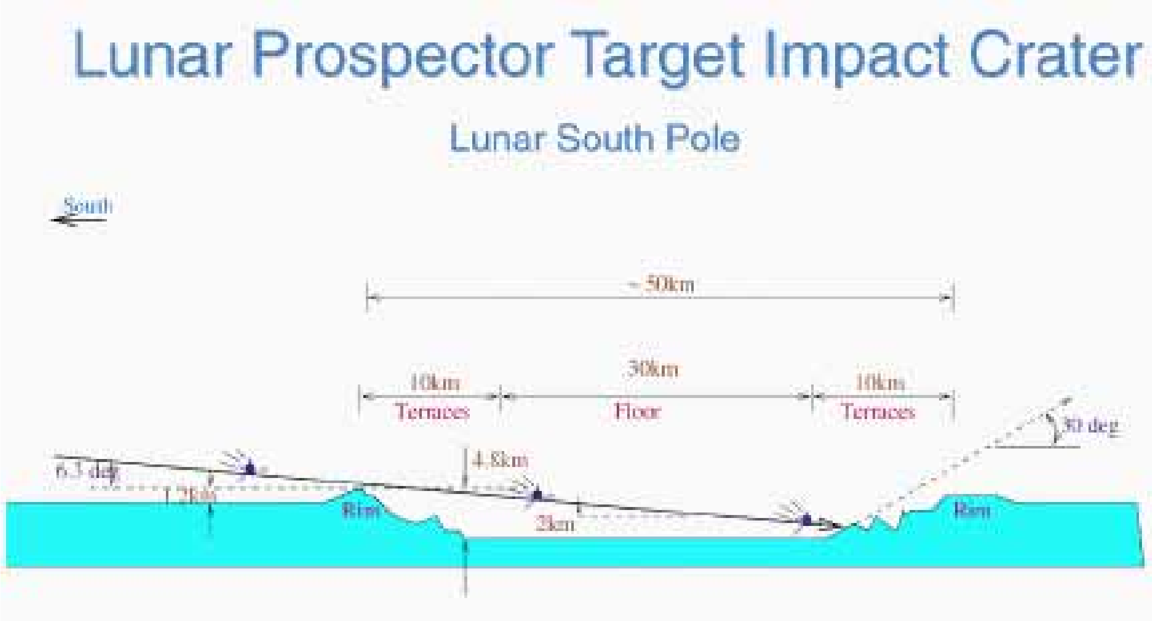
End of Mission Profile

After a year and a half of ground breaking science, and nearing the end of its useful lifetime, Lunar Prospector will take a bold step towards furthering its science legacy by intentionally impacting a targeted south polar crater of the Moon. This final experiment, led by a team from the University of Texas/MacDonald Observatory and coordinated with the Lunar Prospector science team, the Hubble Space Telescope (HST), Hawaii's Keck telescope, the Submillimeter Wave Astronomy Satellite (SWAS) and others, has a slim possibility of total success. However, the cost is small and the potential pay-off is enormous, a fitting finale for one of the lowest cost, most successful space missions ever flown. If all goes well, Lunar Prospector's contributions to the advancement of lunar science will include conclusive evidence of water on the Moon.

Prospector's final experiment consists of a series of events which begins on July 26, when, Lunar Prospector's orbit will be raised slightly to permit the spacecraft to stay in orbit for an additional 5 days to allow the moon's rotation to align the target crater with LP's orbit ground track. Before Prospector can go any further, however, it must first endure a long Earth eclipse period that will be the biggest challenge to its survival since it was launched a year and a half ago. In fact, the January launch date selected for LP was chosen in part to permit the spacecraft to complete its mission prior to July 1999, when the moon was predicted to pass behind the shadow of the Earth as it crosses the ecliptic plane in its monthly orbit. To economize on spacecraft costs, the LP battery was designed to handle maximum shadow periods of 47 minutes before being recharged by solar arrays mounted on the side the spacecraft. During the July 28 eclipse, the LP will pass in and out of regions of partial and total Earth/moon shadows for nearly 3 continuous hours as it orbits the Moon. Prospector components will experience temperatures beyond their normal operating range as the battery runs down to dangerously low levels and is unable to operate electric heaters on the spacecraft. There is a possibility that key subsystems required to operate the spacecraft may be damaged and control of the spacecraft might be lost.



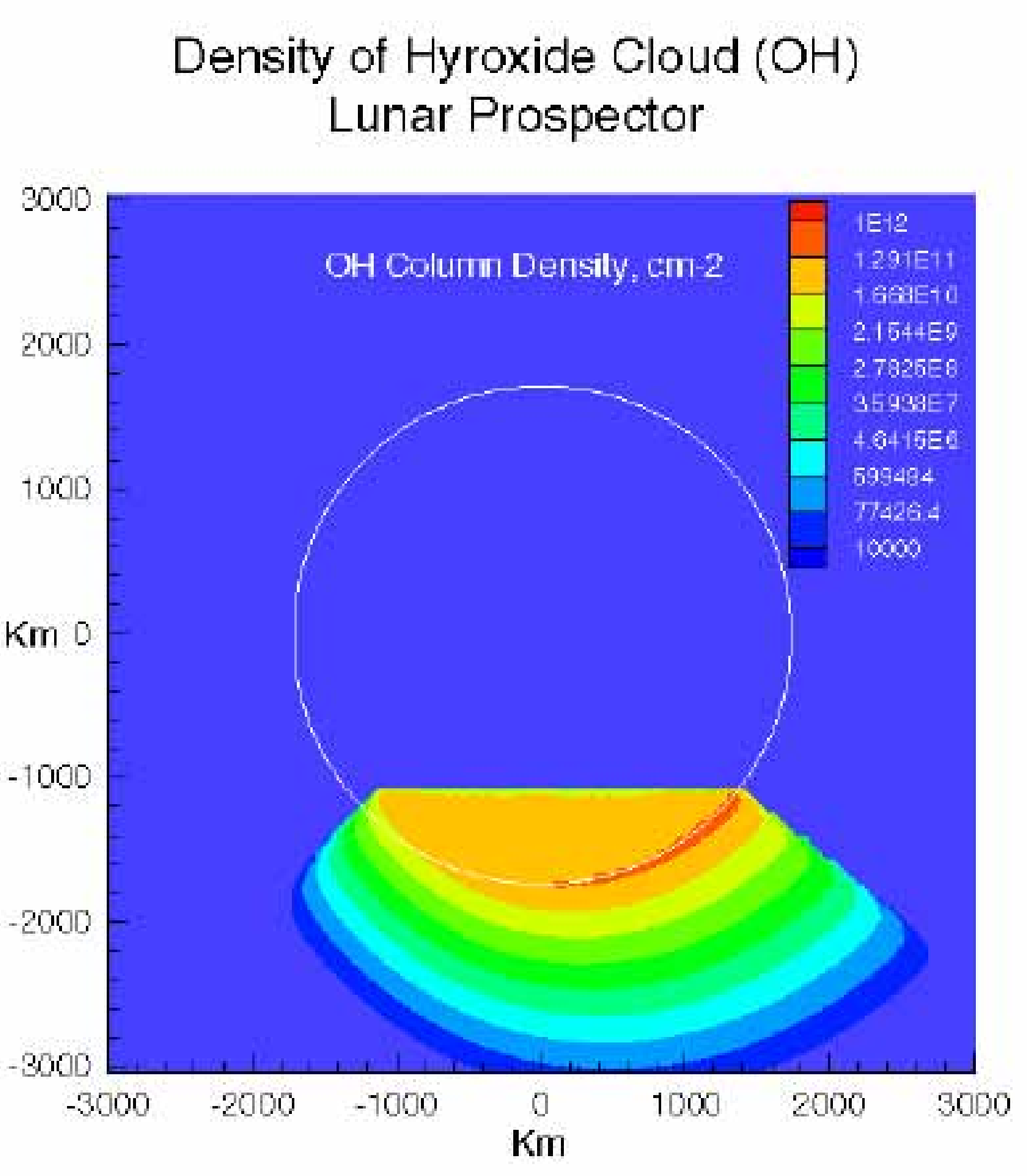
If, as expected, Prospector does survive the eclipse, the timeline for the experiment will proceed on July 29, when the spacecraft will be spun up from 12 RPM to 24 RPM. The increased spin rate will ensure that the small amounts of fuel remaining in LP's tanks will be properly distributed within the propellant system and available for use in upcoming critical orbit maneuvers. Next, on July 30, an initial 4-minute maneuver will loft LP into a higher, 230 km maximum altitude orbit, and will be followed a day later by a second, 5-minute burn of LP's 5 lb thrusters to send the spacecraft on a collision course with the crater. This timed series of burns will use the remaining fuel onboard the spacecraft to maximize the angle of attack of the impact trajectory in order to increase the chance of clearing the rim of the 50 km wide by 4 km deep crater, and to maximize the depth of the impact so as to excavate as much soil as possible.



This schematic diagram shows the Lunar Prospector final target crater.

The final burn commands will be sent before the spacecraft slips behind the Moon for the final time and loses communications with the Earth. This last set of commands will include a time-delayed command that will tell the spacecraft precisely when to fire its thrusters for the final blast into the crater. LP will execute this burn midway across its final journeys over the far side of the moon. The spacecraft will not be seen again before it impacts the lunar south pole.

If all goes as planned, on July 31, 1999 at 05:51 Eastern Daylight Time (09:51 GMT), Lunar Prospector will plunge into the depths of a south pole crater, and collide with the floor of the crater at a speed of 3800 mph. If LP is on target and ice does exist in shadowed regions of the crater as the Lunar Prospector data suggest, the impact is expected to result in a cloud of debris and water vapor large enough to be seen by the powerful telescopes in space and on Earth. Among the telescopes scheduled to be trained on the event are the 2.4 m HST, the .6 m telescope of the SWAS, the 10 m Keck telescope in Hawaii, and the 2.7 m telescope of the McDonald Observatory in Texas.



This diagram shows the likely size distribution, and density of the detectable OH vapor cloud which could be created by a successful impact.

Within the first few seconds of impact, a small debris plume of lunar soil is expected to clear the walls of the crater and may be detected by large telescopes in the visible range. Over the next few minutes, based on some estimates of the expected concentration of ice in the soil of some lunar craters, a cloud up to 87 kg of water ice could be ejected and vaporized by the impact. This water vapor plume should be detectable by infrared instruments over a period of one or two minutes, until ultraviolet radiation from the sun begins to break up the water molecules into H and OH molecules. Eventually, as the impact plume rises further and spreads, all water will be dissociated and for the next 14 hours telescopes should be able to detect the presence of OH molecules in the ultraviolet frequency range.

The challenges of successfully completing this final complicated mission of the Lunar Prospector spacecraft are quite formidable. Assuming the spacecraft does survive the July 28 eclipse, the outcome is by no means certain, given the constraints imposed by the sparse data available on the topography of candidate craters at such high latitudes, and given limited amounts of fuel available to effectively target the crater. However, the potential benefits of success are also high. Water vapor may be directly detected by its infrared signature, or indirectly detected through the presence of an OH plume in the ultraviolet spectrum. In either case, these results will constitute further compelling evidence of the significant quantities of water that have been suggested by LP measurements obtained over the course of close to 50 million miles logged in orbit around the moon. Of course, a negative result will tell us nothing one way or the other about potential lunar water resources. The spacecraft could miss the crater entirely; it could impact high up the inner rim; it could miss a water deposit. Many things could go wrong. Still, it is befitting of this extremely productive little spacecraft, that even in its final act, Lunar Prospector may serve yet once more as a source of knowledge about our Moon.

Possible Results

It is important to remember that the final impact of the Lunar Prospector spacecraft into a permanently shadowed south polar crater can only demonstrate a positive result. That is, if no vapor cloud is created, this will only indicate that something was misunderstood about the impact. The experiment cannot prove that there is no water ice at the poles. It can only show that there is water or that something went wrong. Still, the possible results from this experiment are tremendously exciting.

There are several possible outcomes of an observational program that is a one-shot, time- critical event with little opportunity for pointing corrections or practice runs:

(a) H_2O or OH molecules are detected--Prospector struck and vaporized some water ice providing proof positive of the presence of water ice at the impact site.

(b) No significant gas emissions are observed, despite apparently successful execution of the experiment-- (1) preliminary assumptions and/or calculations about the nature of the vapor plume were inadequate; or (2) there was not enough vapor to be seen, and therefore, either there was little or no water ice at the specific impact site or, perhaps, in the entire crater. This could, potentially mean that the hydrogen atoms that appear in LP's data in the cold trap areas are in a form other than water ice.

(c) No significant gas emissions are observed-- (1) there was a premature impact with a cold-trap crater rim; (2) the spacecraft struck a large, hard rock out-cropping; or (3) poor observing conditions or instrumental failures at prime observing facilities prohibited taking of data.

Implications

The importance possible ice reservoirs in cold traps near the poles of the Moon is clear: large volatile reservoirs could potentially aid human exploration of space. The Moon is, in many ways, an ideal platform from which to do space science and astronomy. A lunar outpost, supported by a reserve of water, becomes a more realistic possibility. Many in the science community consider the Moon a viable platform from which to launch solar system exploration missions such as a mission to Mars. Finally, the water ice itself, preserved in cold traps on a billion year time scale, may hold a record of cometary impacts. It is conceivable that core samples could be taken and analyzed, providing valuable insight into the history of the solar system and the nature of comets and water rich asteroids.

The Lunar Prospector mission using the neutron spectrometer appears to have found ice at both poles. Future rover or manned missions are likely to focus on the distribution of this ice. It is important, however, to be sure that the detected subsurface hydrogen is really due to water ice. Prospector’s final contribution to science could be a confirmation of this inference. The experiment itself may also serve as a proof-of-concept approach for other missions which may use an impactor to search for volatiles (or other materials). For example, other expendable spacecraft in high Earth orbit could be redirected for lunar impact for similar purposes. The key is to identify a suitable vehicle which is no longer functioning adequately for its intended mission but which remains controllable and has sufficient fuel to reach the Moon. If such a vehicle exists, it would deposit about ten times the Prospector kinetic energy upon impact and could be directed to impact more nearly normal to the surface.

End of Mission Timeline

All times are UTC. Subtract 7 hours for PDT. These numbers are the results of preliminary mission analysis studies and are within 2-3 minutes uncertainty.

TIMES	EVENTS
IMPACT (I) - 59 days June 2, 1999	Extended Mapping Orbit Correction maneuver #6 (EMOC#6) completed on June 2, 1999 to return the orbit to its nominal 30 +- 15 km. altitude profile for another 27.3 days.
I - 36 days June 25, 1999	Current Moon shadow season ends.
I - 32 days June 29, 1999	EMOC#7. This Orbit Correction returned the orbit to the extended mission altitude profile (30 ± 15 km). The correction amounts to two velocity adjustments spaced half an orbit apart. _V1 (change in velocity) is 7.3 m/sec at about 15:11 UTC and _V2 is 7.5 m/sec at about 16:22 UTC. The maneuver used jets A1/A2 (located on the bottom of the S/C opposite the antenna).
I - 14 days July 17, 1999	Moon shadow season began again.
I - 5 days July 26, 1999	EMOC#8. Since the mission will end on 7/31 there is no need to do a complete orbit correction but without a small adjustment the orbit will continue to decay and impact is possible within 2 days. A 10.5 second 1.4 m/sec velocity burn (jets A1/A2) will be performed at apoapsis (point of furthest distance from Moon) (about 15:18 UTC) to raise periapsis (point of closest approach to Moon) about 7 km. This maneuver will assure the periapsis will not fall below 10 km.

	altitude for the remaining five days.
I - 3 days July 28, 1999	Earth Eclipse- LP will experience both penumbral (partial shadow) and umbral (total) eclipse during this event. Note: LP will also experience Moon shadow for a duration of 35 minutes during the Earth eclipse. Nearly two full Moon shadow periods will occur during the 3 hour, 25 minute Earth penumbral period. Nominal UTC times: 08:00 start commanding (instruments will be commanded off to save power) 08:37 enter Moon shadow (S/C goes behind Moon) 09:02 enter Earth penumbra 09:13 exit Moon shadow (S/C emerges: transmitter may be off) 09:32 exit Earth penumbra 10:16 enter Earth penumbra 10:29 enter Moon shadow 10:53 enter Earth umbra 11:05 exit Moon shadow 11:37 exit Earth umbra 12:20 enter Moon shadow 12:56 exit Moon shadow 13:43 exit Earth penumbra 15:00 End commanding
I - 2 days July 29, 1999 15:32 UTC (8:32 am PDT)	Start commanding spin trim.
I - 2 days July 29, 1999 15:32 UTC	Spacecraft will be spun up from 12 RPM to about 24 RPM to ensure that remaining propellant is distributed to propellant feed lines in preparation for the crater targeting maneuvers. The spinup will be performed about 6 orbits before the first crater targeting maneuver to provide undisturbed tracking and assure

(8:32 am PDT)	the best orbit determination (OD) is available for the apoapsis raising maneuver on July 30, 1999.
I - 1 day July 30, 1999 07:45 UTC	Start commanding apoapsis raising burn.
I - 1 day July 30, 1999 08:17 UTC (1:17 am PDT)	A 250 second burn with a velocity of 39.6 m/sec (jets A3/A4) will raise the apoapsis altitude to 232 km. This raising of the orbit at one end and the subsequent lowering of the orbit at the other end is done to maximize the angle at which the S/C will fly into the crater. A higher angle will minimize the chance of hitting the rim of the crater, and maximize the depth of the impact. This maneuver will be executed in view from the Earth unlike the final burn which is executed behind the Moon just prior to impact. As the result of this maneuver the Moon shadow terminates. The time of this maneuver has been selected to assure the impact falls within the Hubble space telescope view period of 09:42 to 10:18 UTC on July 31, 1999.
I - 11 hours July 30, 1999 23:00 UTC (4pm PDT)	Moon shadow event starts again.
I-5 hours July 31, 1999 05:12 UTC (10:12 pm July 30th PDT)	MacDonald Observatory at Austin Texas focuses on the lunar south pole. MacDonald has the capability to detect OH in the Ultraviolet (UV) spectra. The vapor cloud created by the impact could last some 13-14 hours. These data, if detected, would take from 2-4 weeks to integrate and from 1-3 months to analyze for a definitive result.
I-2 hours July 31, 1999 08:16 UTC (1:16 am PDT)	Keck Telescope in Hawaii focuses on the lunar south pole. Keck has capability to detect a possible short-lived debris plume in the visible range. This plume, if discernable, might last 1-3 seconds. Keck also has instrumentation to detect a possible short-lived vapor plume in the near Infrared (IR). This plume, if discernable might last ~ 2 minutes. In addition, Keck has capability to detect OH spectral lines in the UV range.
I-67 minutes July 31, 1999 08:44 UTC	Start commanding for final burn.

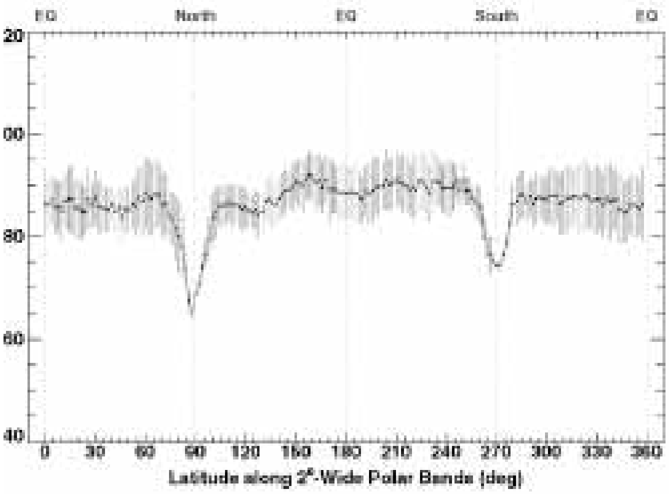
(1:44 am PDT)	
I - 40 minutes July 31, 1999 09:11 UTC (2:11 am PDT)	LOS- Loss of Signal. Mission Command and Control (MCC) will lose signal as the S/C slips behind the Moon
I — 35 minutes July 31, 1999 09:16 UTC (2:16 am PDT)	Final burn of 45.5 m/sec (jets A3/A4) will target LP for the crater impact. This maneuver will be executed behind the Moon. The 285 second burn reduces periapsis altitude from +17 km. to -166 km (sub-lunar).
I-10 minutes July 31, 1999 09:42-10:18 UTC (2:42-3:18 am PDT)	Hubble Space Telescope (HST) focuses on the lunar south pole. HST has capability to detect OH spectra in the UV. H_2O will immediately begin breaking down into OH and the vapor cloud will be detectable in the UV range. This will still constitute a clear indication of water ice at the pole. The vapor cloud created by the impact could last some 13-14 hours. These spectra, if detected, would take from 2-4 weeks to integrate and from 1-3 months to analyze for a definitive result.
IMPACT July 31, 1999 09:51 UTC (**2:51am PDT**)	The nominal impact point is at a radius of 1733.8 km (-4.2 km altitude which is believed to be the bottom of the target crater), latitude of -87.7 deg and longitude of 42 deg E. The impact velocity is about 1.69 km/sec (3,780 mi/hr).
I + _ 10 minutes July 31, 1999	A debris plume in the visible range is detectable. This plume, if discernable, might last up to several minutes.
I + _ 30 minutes July 31, 1999	A vapor plume (H_2O) in the near IR is detectable. This plume, if discernable, might last 10-30 minutes.
I + _ 12 hours July 31, 1999	A thin atmosphere of OH dissociated from H_2O by sunlight is visible in the UV. This exosphere could last several hours
I + „ 2weeks	OH spectra and other mission data are integrated and analyzed.

Summary of Scientific Results to Date

Since earlier results were reported in March and September of 1998, scientists have continued to collect and process data from the spacecraft at both the 100 km primary mission altitude and the 30 km extended mission altitude. In particular, with data collected at the lower orbit, LP scientists have been able to map the moon with greater resolution, allowing them to announce exciting new findings and to improve their understanding and models of the moon.

Neutron Spectrometer Experiment Results:

As reported in March and September of 1998, LP mission scientists have been able to establish the existence of significant concentrations of hydrogen at the lunar poles based on telltale dips in the epithermal neutron energy spectra sent back to Earth by Prospector’s Neutron Spectrometer (NS). If, as some scientists suspect, this excess hydrogen exists as part of frozen water molecules buried in permanently shadowed craters at the lunar poles, there could be as much as 260 million metric tons of water ice (75 billion gallons of water) on the Moon.



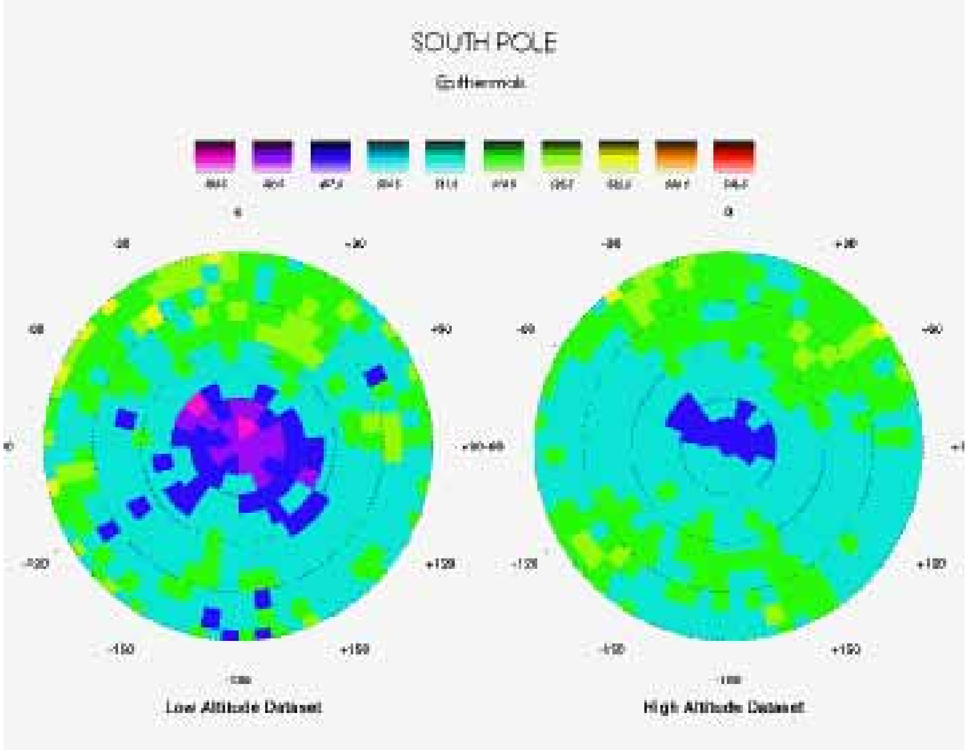
Los Alamos National Laboratory

Medium energy neutron counts (LP data) showing the two polar dips which indicate water ice.

Lunar Prospector is the very first interplanetary mission to use neutron spectroscopy to detect water, and thus scientists must create new models that describe how neutrons on the lunar surface behave and refine those models in order to match the characteristics of data collected by Prospector. With the new higher resolution NS data collected at the 30 km extended mission altitude, scientists have been able to improve on their earlier models and estimates, and in some cases are now able to pinpoint the location of potential ice deposits. The latest findings of the Neutron Spectrometer experiment include:

- Higher resolution NS data taken at the lunar South pole, which contains more permanently shadowed areas where larger concentrations of ice deposits are presumed to exist, have allowed scientists to develop better estimates of the location and concentration of hydrogen deposits that are believed to exists in the form of water ice. Scientists believe that as much as 200 million metric tons of water ice could be mixed in with the lunar regolith in shaded craters of the South pole of the moon. These ice deposits, if they exist, are now believed to lie within 5 cm of the lunar surface in concentrations of approximately 1.5 %.

- Current data suggest that as much as 60 million metric tons of water ice could exist at the North lunar pole. Because permanently shaded craters in the North pole are fewer and smaller, less information can be derived on composition of such deposits, despite the higher resolution provided by the extended mission orbit. However, other than the size of the deposits, there is no reason to believe that North and South pole ice deposits differ in their mixture ratios or depth within the lunar regolith.
- Neutron spectroscopy has proved useful in mapping, not only hydrogen but also iron and titanium. In addition, some effects in the thermal neutron data can be attributed to elemental absorbers. Gadolinium and Samarium are likely candidates.



LP Neutron Spectrometer data comparing the extended mission data set (low altitude) with the primary mission data set (high altitude).

Gamma-Ray Spectrometer Experiment Results:

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)

silicon (Si)

aluminum (Al)

calcium (Ca)

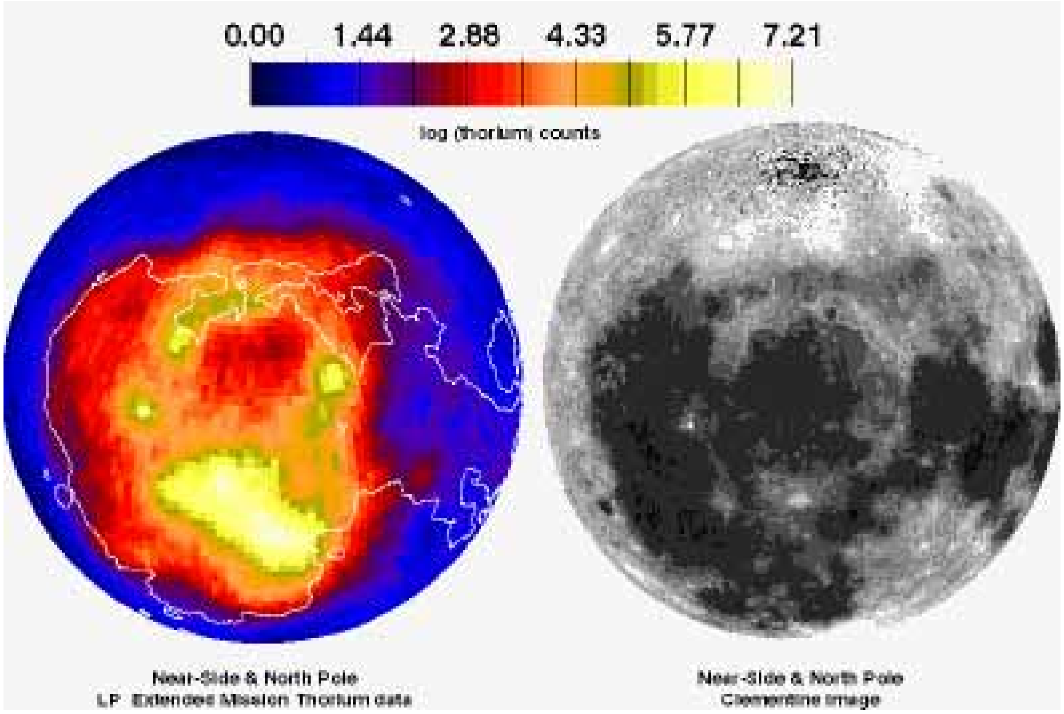
magnesium (Mg)

oxygen (O)
titanium (Ti)

The GRS is especially sensitive to the heavy, radioactive element thorium and the light element potassium. These are particularly plentiful in the last part of the crust 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. Specific results of this experiment include:

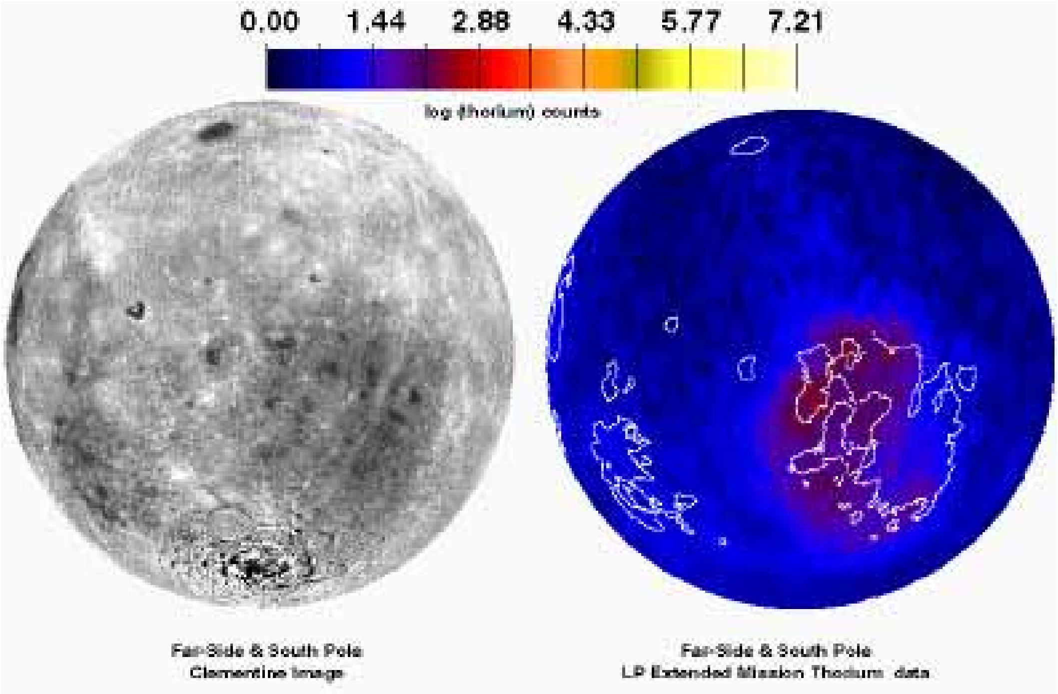
- The Lunar Prospector Gamma-Ray Spectrometer (GRS) has acquired the first global measurements of gamma-ray spectra from the lunar surface. Since gamma-rays coming from the lunar surface carry information about lunar elemental composition, this data set comprises the first direct elemental composition measurements that have been made for the entire lunar surface. Specifically, global information has been gathered on the distribution of key elements, including Iron and Titanium, along with trace elements associated with lunar KREEP (K-potassium, Rare Earth Elements, and P-phosphorous) material. The global distribution of three major lunar rock types (mare basalts, noritic rocks, and anorthositic rocks) has been compiled.
- This global mapping has provided further insight into the mechanisms underlying the distribution of various elements about the Moon --- in particular the excavation and deposition of KREEP via lunar impact events.

It has long been known that a full understanding of the surface elemental composition of the Moon will significantly improve our understanding of lunar formation and evolution. For example, one long-standing issue of lunar formation that can be addressed with global composition data concerns the elements aluminum, uranium, thorium (refractory elements) and iron oxide content of the Moon. There are suggestions from Apollo, Galileo, and Clementine data that the Moon is enriched, that is has greater abundances of these refractory elements and iron oxide compared to the Earth. If the Moon indeed has such enrichments, then lunar origin models which assume that most of the Moon’s material comes from the Earth’s mantle (such as the giant impact hypothesis) would be incorrect. Another issue that can be addressed using composition data concerns the variability and evolution of the lunar highlands as traced by the material KREEP. KREEP, associated with thorium, is a material thought to have formed between the lunar crust-mantle boundary, so its distribution on the lunar surface can give information about how the lunar surface has evolved over time. The following two sets of images show LP thorium data side-by-side with Clementine images of the Moon’s near and far sides. White outlines on the data half of the image delineate the lunar maria and highlands boundaries. The nearside LP image clearly indicates that most of the thorium is concentrated on the near-side mare in and around Mare Imbrium. In addition, while it is known from Apollo sample returns that some of the thorium south of Mare Imbrium was produced by volcanic activity, these images also appear to show that some part of the thorium was spread on the lunar surface as a result of the impact that produced the Imbrium basin.



A comparison of LP’s nearside thorium data and a corresponding image of the Moon.

The far side image makes an interesting comparison to the nearside image. The South-Pole Aitken Basin, which is the largest known impact basin in the solar system, is located on lunar farside (as indicated by the dark area in the farside Clementine image). Because this basin is so big, the impact that produced it must have dug much deeper into the Moon than any of the impacts on the nearside. The LP data, however, only shows a small amount increased thorium in this area. Since the lunar crust is thicker on the farside than on the nearside, it is possible that the impact which produced the SPA basin never dug deep enough to dredge up much thorium.



A comparison of LP’s farside thorium data and a corresponding image of the Moon.

In addition to mapping thorium and other elements, a number of other lunar science issues can be addressed using GRS data; these include: 1) Identifying and delineating basaltic regions in the lunar maria using maps of iron and titanium composition; 2) Determining the composition of hidden or "Cryptic" mare regions that were originally found in the lunar highlands using Clementine data; 3) Identifying and delineating highland petrological regions; and 4) Searching for anomalous areas with unusual elemental compositions that might be indicative of deposits with resource potential.

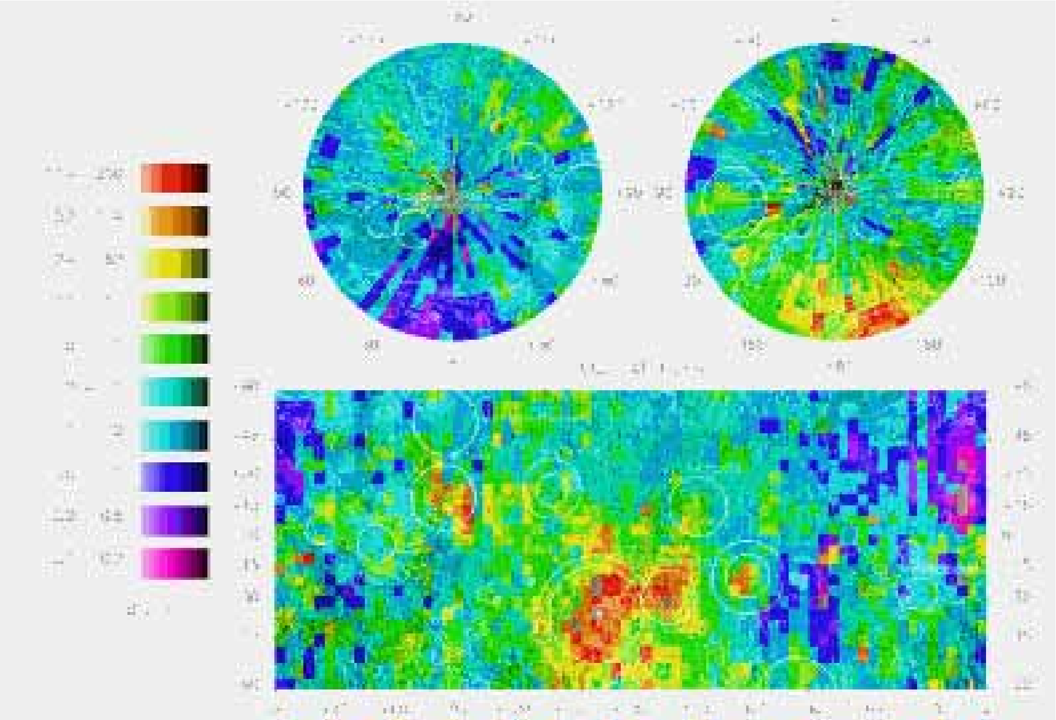
When this map is compared to data obtained by both the LP neutron spectrometer and earlier Clementine data, it is seen that all of the known regions of high-iron concentrations are identified with this LP GRS data. For example, high-iron concentrations are seen in the near-side mare, the south pole Aitken Basin, and Mare Australe. Interestingly, we also see high counts in regions not known for having high-iron content. There are indications from LP thermal neutron data that some of these discrepancies with the Clementine data may be the result of iron deposits in these regions having a mineralogical form not observable with the Clementine infrared spectra.

There also appear, however, to be regions of high-iron-count rates on the lunar farside that are not seen in either the thermal neutron data or the Clementine data. Most of this region is lunar highlands thought to be relatively high in aluminum abundance. Since the aluminum gamma-ray line (7.72 MeV) is one of the only gamma-ray lines that can produce an interference with the iron lines (7.6 MeV), this suggests that some of these high-count-rate regions may be due to high aluminum abundances. It should be stressed that this is only a preliminary conclusion. A full analysis of the entire gamma-ray spectrum needs to be completed before final conclusions can be drawn.

Magnetometer/Electron Reflectometer Experiment Results:

The MAG/ER experiment relies on a Magnetometer for measurements of the Moon's global magnetic field in space and an Electron Reflectometer for measurements of localized magnetic fields on the surface of the Moon. The ER derives information on the Moon's surface magnetic fields by analyzing electrons that are reflected by the lunar magnetic field. For the most part, however, such solar wind electrons can only be detected a few days each months (around full Moon periods) when the Earth passes between the Sun and Moon, thereby providing a quiet magnetic environment. One year of primary mission data at a 100 km altitude has been supplemented with higher resolution data at the 30 km altitude extended mission altitude. Key observations and results to date have been as follows:

- **Global distribution of crustal magnetic fields from electron reflectometry:** Prior to LP, the Apollo 15 and 16 subsatellites obtained electron reflection measurements within ~35 degrees of the equator. With fewer than 10,000 points, the surface was undersampled by a factor of 35. By mission's end, the MAG/ER on LP will have obtained more than 700,000 electron reflection measurements distributed over the entire Moon, and the under-sampling factor will be reduced on average to 1.8. This is sufficient to map most of the lunar surface at 3-degree resolution and some regions at 0.5-degree (15 km) resolution. The resolution along the orbit track is as fine as 5 km.



Extended Mission E/R data

It was known from the Apollo measurements that the maria are generally more weakly magnetized than the highlands. Lunar Prospector measurements have shown that there are systematic variations in magnetic field strength over the different mare units, ranging from ~0.1 nanotesla (nT) over Imbrium TO a few nT over Tranquillitatis. Since the mare fills are thin (~1 km), the existence of these variations implies that the magnetized layer is also thin.

The largest concentrations of strong magnetic fields are on the lunar far side, diametrically opposite (antipodal) to the Imbrium, Serenitatis, Crisium, and Orientale impact basins. The basin rock itself is weakly magnetized, which implies that large basin-forming impacts demagnetize the crust at the impact site, while simultaneously magnetizing the crust on the opposite side of the Moon. Lunar Prospector measurements have shown that a number of other impact basins exhibit weaker magnetic fields than their surroundings, including Nectaris, Hertzsprung, Schrodinger, and Humorum. However, these smaller basins have no antipodal magnetic enhancements, suggesting that only large, young impacts are capable of the antipodal magnetization effect.

In addition, there are hundreds of smaller magnetized regions scattered over the entire Moon, with surface field strengths ranging from several nanotesla to over 300 nT. Efforts are underway to search for systematics in the surface field distribution.

- **Direct measurements of crustal magnetic fields from orbit:** Before LP, direct measurements of crustal magnetic fields consisted of a few surface observations at the Apollo landing sites and measurements by magnetometers on the Apollo sub- satellites. (These measurements were also confined within ~35 degrees of the equator.) Most of the subsatellite measurements were obtained at high altitudes (> 75 km). However, some low-altitude (< 25 km) data were acquired in a narrow strip across the central near side prior to the impact of the Apollo 16 subsatellite onto the lunar surface. The latter measurements revealed an especially strong local anomaly over Reiner Gamma, an unusual swirl-like albedo marking on western Oceanus Procellarum.

The LP primary mission yielded 100-km-altitude measurements over the entire surface. Because of the weakness of crustal fields at this altitude (of order 1 nT) and the existence of temporally varying external magnetic fields, only the strongest fields were mapped in detail. However, during the final 8 months of the LP mission, the spacecraft mean altitude was lowered and higher-resolution measurements were obtained at altitudes as low as 15 km. At these lower altitudes, one strong crustal source, Reiner Gamma, produced a 45-nT signal at the spacecraft altitude of 18 km, and many other sources were observed, including the Sirsalis Rille and the antipodal zones of Imbrium, Serenitatis, Crisium, and Orientale. These data are currently being analyzed to determine whether other albedo markings similar to Reiner Gamma on the far side are associated with equally strong local anomalies.

- **Solar wind interaction with crustal fields:** The Explorer 35 and Apollo subsatellites found amplifications of the solar wind magnetic field downstream of strong crustal magnetic fields. However, the equatorial orbits of those spacecraft allowed observations only at the periphery of the interaction region, where the exact nature of the interaction could not be established.

LP's polar orbit carried the spacecraft to all latitudes and thus, into the heart of the interaction region. There, MAG/ER measurements established that miniature magnetospheres were forming around concentrations of strong crustal magnetic fields that occur diametrically opposite to the Imbrium, Serenitatis, Crisium, and Orientale impact basins. This observation is significant because it shows that in addition to being strong (> 50 nT at the surface), the crustal sources must also be coherent over ~100-km length scales.

A remarkable property of these miniature magnetospheres is that they sometimes disappear! Using a statistical analysis, we found that whether or not a magnetosphere forms depends on the temperature of solar wind protons. When the protons are cold, the solar wind behaves as a fluid around the crustal magnetic field, and a magnetosphere is formed. When the protons are too warm, the solar wind behaves as a collection of individual particles, and no magnetosphere is formed.

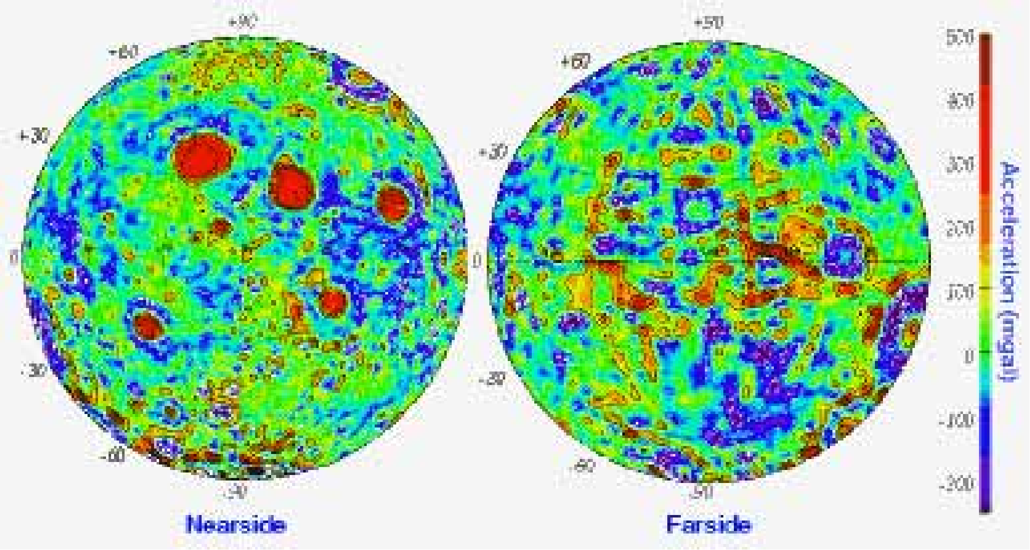
- **Lunar Core:** Initial measurements of the lunar induced magnetic dipole moment have been obtained using Prospector magnetometer data from April 1998 when the Moon was in a lobe of the geomagnetic tail. These measurements, which may be refined after further analysis of later Prospector data, are consistent with the presence of a metallic core with a radius between 250 and 430 km. This is compatible with independent evidence from gravity and laser ranging data, which suggest a ~300-km-radius core.

Doppler Gravity Experiment Results:

The extended mission with its lower altitude has provided the Doppler Gravity Experiment (DGE) with the means to generate an improved lunar gravity model, uncover additional mascons ("mass concentrations") and further refine our understanding of the moon's interior. Since December of 1998, the Lunar Prospector has been successfully lowered to orbits with mean altitudes of 40 km and eventually 30 km, where gravitational perturbations to the orbit are more pronounced. At each orbit, improved lunar gravity models were developed which enabled spacecraft controllers to maintain Prospector in orbit with more precision than any preceding lunar orbiting spacecraft. So accurate were the models that maneuvers could be planned 4 weeks in advance and their frequency stretched to within a few days of impact in order to minimize fuel use.

While extended mission Doppler data continues to be processed, results of the DGE to date include:

- **Gravity Model:** A high resolution 100 degree and order gravity model of the moon has been generated. Relative to the most recent LP 75th degree and order spherical harmonic solution (presented in Science, Sept. 98), this improved model shown below represents an increase in the number of parameters from 5,800 to 10,200 and an improved resolution of the corresponding half wavelength from 2.4 degrees (72 km) to 1.8 degrees (54 km).



The final gravity map based on Lunar Prospector Extended Mission data

- **Lunar Core:** The LP gravity experiment, when combined with Lunar Laser Ranging data from previous missions, has improved the knowledge of the Moon's polar moment of inertia by a factor of 5. This more accurate knowledge suggests that the moon has an iron core with a radius of 300-400 km.

- **Lunar Mascons:** From the Apollo and Lunar Orbiter missions in the late 60's and early 70's, were discovered on the Moon for the large nearside impact basins that were filled with lava. To date, LP has uncovered 13 more mascons. Surprisingly, mascons also exist for large impact basins (>300 km diameter) that do not have any evidence of lava fill. Another unexpected result is that mascons are being partially resolved on the lunar farside even though LP can not observe the lunar farside gravity directly.

The lunar gravity field together with the shape of the Moon provides details on the thermal history and interior of the Moon. This includes, for example, the core, large scale structure in the mantle, crustal thickness variations, lithospheric strength, mascon formation, and small crater structure. LP has determined the gravity field to a very high resolution (~30 km) for about 60% of the lunar surface. When the high resolution LP gravity model is combined with topography data of the Moon, obtained primarily from the laser ranging experiment aboard the Clementine spacecraft and refined by improvements from Earth-based radar interferometry and Clementine stereo imaging elevation models, scientists can begin to understand the evolution of the moon. Research on the interior of the Moon will be forthcoming over the next few years as geophysicists analyze these models.

- Lunar Prospector’s high quality gravity data, improved by roughly a factor of five over previous estimates, indicate the existence of a lunar core, probably iron, with a radius of more than 300 km.

Such improvements to the lunar gravity field also offer the practical benefits of modeling long-term spacecraft orbits about the Moon, which allows more accurate planning of future mission fuel needs and enables the development of fuel efficient orbital maintenance strategies. LP engineers are currently relying on the improved lunar gravity model in devising strategies for maintaining LP's extremely low orbit during the extended mission phase.

Alpha-Particle Spectrometer Experiment Results:

The Alpha Particle Spectrometer aboard Lunar Prospector has been collecting voluminous high quality data since the start of the primary mission. There are, as yet, no published results, however. The APS experiment has experienced even more solar activity than was predicted. In addition, the spectrometer has worked so well that where mission scientists hoped to get 5 data counts per 32 second integration period, there are 3000 to be analyzed. The analysis for the APS will, no doubt, take at least two years. When the results become available, however they will likely provide insight into solar physics as well as the Moon.

SCIENTISTS' BIOGRAPHIES

Dr. Mario Acuña (LP Co-investigator, 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.

J. Victor Austin

Victor Austin received his BS in mechanical Engineering from Duke University in Durham

North Carolina in 1990. He then attended George Washington University, studying fluid dynamics. He is currently completely his PhD in Aerospace Engineering at the University of Texas at Austin. Since 1996, he has been a NASA research fellow in planetary atmospheres.

Dr. Edwin S. Barker (University of Texas at Austin, Austin, Texas)

Dr. Barker has been a research scientist at the University of Texas at Austin McDonald Observatory for nearly 20 years and is currently the assistant director for telescope scheduling. From 1995-1996 he served as discipline scientist in planetary astronomy at NASA headuarters. He obtained a B.S. in physics (with a minor in math) from New Mexico State University in1962. He went on to earn an M. A. in Astronomy from the University of Kansas (1964) and a Ph.D. in Astronomy from the University of Texas at Austin in1969. He has produced over 91 publications in refereed journals, primarily on the atmospheres and surfaces of planets, and on asteroids and comets. He has sat on numerous review panels and is currently a member of the Planetary Astronomy Operations Working Group (PAMOWG).

Dr. Alan Binder (LP Principal Investigator, Lunar Research Institute, Tuscon, AZ)

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 (LP Co-investigator 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. David B. Goldstein (University of Texas at Austin, Austin, Texas)

Dr. Goldstein is the Principal Investigator for Lunar Prospector's controlled impact experiment and teaches at the University of Texas at Austin. He received his BSE with honors from Princeton University in 1984 and went on to earn both a Master's degree (1985) and a PhD (1990) in Aeronautics from the California Institute of Technology. Before coming to the University of Texas, he was a research associate in applied math at Brown University in Providence, Rhode Island. He is currently an associate professor of aerospace engineering & engineering mechanics at the University of Texas at Austin. His technical interests include rarefied gas dynamics and direct simulation modeling and experiment, planetary atmospheres, molecular collision dynamics, unsteady cavity flows and passive nose-tip cooling mechanisms. In addition, he has worked with parallel computation and parallel algorithms, programming, turbulence simulation and application of riblets and MEMS for drag reduction, and spectral methods.

Dr. Lon Hood (LP Co-investigator 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 (LP Co-investigator 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 ((LP Co-investigator, 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.

Dr. Robert Steven Nerem (University of Texas at Austin, Austin, Texas)

Dr. Nerem joined the UT faculty in January 1996 after spending over 6 years at NASA/Goddard Space Flight Center as a geophysicist. He received his B.S. degree in Geology from Colorado State University in 1982, and his M.S. and Ph.D. degrees in Aerospace Engineering from The

University in 1985 and 1989 respectively. Dr. Nerem also worked for NOAA and the Jet Propulsion Laboratory during his graduate training. He has more than 30 refereed journal articles and 11 refereed conference publications covering a variety of topics in satellite orbit determination, geophysics, oceanography, and planetary science. In addition, he has co-authored a chapter for a book on the gravity field and co-edited a book on gravity field determination. He has served as an Associate Editor of the *Journal of Geophysical Research - Solid Earth*, and currently serves as Geodesy Editor for *Eos Transactions* of the American Geophysical Union. He also was awarded an Editors' Citation for Excellence in Refereeing by the journal *Geophysical Research Letters* in 1993. Dr. Nerem is a specialist in satellite orbit determination, satellite remote sensing, and space geodesy, the latter dealing with measuring the Earth's shape, gravity field, and sea level using space-based techniques. He has also applied these techniques to measuring the gravity fields of Venus and Mars. Dr. Nerem has participated in several NASA flight projects including Lageos II, TOPEX/Poseidon, Jason-1, Pioneer Venus Orbiter, and Mars Observer. In 1995, Dr. Nerem was awarded NASA's Exceptional Scientific Achievement Medal for his research in the area of gravity field determination, in addition to a dozen NASA achievement and performance awards he received while at NASA. Dr. Nerem’s research is currently supported by the National Science Foundation, NASA, the National Imagery and Mapping Agency, and the State of Texas.

GLOSSARY

altitude profile The change in altitude of an orbiting body over the course of its orbit about a planet

apoapsis The furthest point from a planet that an orbiting body travels

_ V The change in velocity required to go from one orbit to another

DOD Depth of discharge; the extent to which the charge on a battery has been depleted.

Eclipse The passing of one orbiting object or planet in the shadow of another

gamma ray A type of high-energy radiation

GMT Greenwich Mean Time

H_20 The chemical designation for water

highlands Heavily cratered, light-colored regions of the lunar surface (the Moon’s oldest rocks)

HST Hubble Space Telescope

IR Infrared; electromagnetic radiation with wavelengths in the approximate range of 1,000-1,000,000 nanometers (10–^{9} meters)

jets Small rocket engines or thrusters used to change the orbit or orientation of a spacecraft

jets A1/A2 A3/A4 Designations of the two pairs 5lb thrusters that fire along the +Z axis (A3/A4) and —Z axis (A1/A2) of the spacecraft

km Kilometer

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

lb Pound

LP Lunar Prospector

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

OH Hydroxide chemical compound that is formed by water when dissociated by UV light

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

penumbra (-al) A region partially shadowed by a planet or object

periapsis The closest point of approach of an orbit about a planet

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

RPM Revolutions per minute

selenology Scientific study of the history of the Moon, as recorded in rocks

umbra (-al) The central, completely dark region of a shadow cast by a planet or object

UTC Universal Time Code

UV Ultraviolet; electromagnetic radiation with wavelengths in the approximate range of 10-400 nanometers (10– 9 meters)

Thumbnails of some of the (publication size) available images which may be found at:

http://lunar.arc.nasa.gov and

http://george.arc.nasa.gov/dx/basket/storiesetc/LPdispix.html