

Lunar Prospector Searches for Polar Ice, a Metallic Core, Gas Release Events, and the Moon's Origin

Alan B. Binder, William C. Feldman, G. Scott Hubbard, Alex S. Konopliv, Robert P. Lin, Mario H. Acuna, and Lon L. Hood

Lunar Prospector, the third mission in the "faster, better, cheaper" NASA Discovery Program, was successfully launched from Cape Canaveral on January 6, 1998 (see <http://lunar.arc.nasa.gov>). Lunar Prospector is now in lunar orbit and is the second Discovery spacecraft to visit a major planetary body in less than a year. Its scientific goals are to map the Moon's surface composition, with special emphasis on the search for polar ice deposits, and its magnetic and gravity fields and determination of the frequency and locations of gas release events. These data will provide a basis for better understanding the current state and resources of the Moon, as well as for further constraints on its origin and evolution.

A programmatic goal of the mission is to demonstrate that high quality science data can be obtained on a simple spacecraft at less than 10% of the cost of previous NASA missions. With a development time of only 22 months and a total budget of \$63 million, Prospector is three to four times less expensive than the other three ongoing Discovery missions and is the first to be peer-reviewed and competitively selected. The first two Discovery missions, Near Earth Asteroid Rendezvous (NEAR) and Mars Pathfinder, were previously defined, low-cost NASA missions that were used to initiate the Discovery series. NEAR performed a successful flyby of asteroid 253 Mathilde in June 1997 and is on its way to a 1999 rendezvous with the near-Earth asteroid Eros. Mars Pathfinder successfully landed on Mars on July 4, 1997. The fourth mission, Star Dust, will be launched in 1999 to collect and return cometary and interstellar dust samples to Earth.

Lunar Prospector is intended to complement the recent successful Clementine spectral imaging mission with more direct compositional and selenophysical measurements that can only be obtained at low altitudes. Because the mission was meant to use a very low-cost, small, simple, spin-stabilized spacecraft with minimal operational requirements, the payload instruments were chosen on the basis of the following criteria: High science value, low data rate, small mass, low power requirement, omnidirectional field of view, and proven capability based on previous missions. The selected instruments are a bismuth germanate Gamma-Ray Spectrometer (GRS), a Neutron Spectrometer (NS), an Alpha Particle Spectrometer (APS), a Magnetometer (MAG), and an Electron Reflectometer (ER). A Doppler Gravity Experiment (DGE) that uses the Doppler tracking data for its measurements was also selected for the mission. Unlike Apollo-era measurement platforms, Lunar Prospector will be in a nearly polar orbit so that global coverage will be possible. The resulting measurement capabilities are closely consistent with those recommended in a series of NASA working group reports [*LExSWG*, 1992].

Lunar Prospector was launched from the Spaceport Florida commercial pad (Pad 46) at the Eastern Test Range. The launch vehicle was a Lockheed Martin Launch Vehicle 2 (Athena 2). Five days after launch, the spacecraft reached the Moon and the first of three Lunar Orbit Insertion (LOI) burns (each lasting nearly 30 minutes) put it into a 12 hour, capture orbit. One day later, the second LOI burn reduced the orbit period to 3.5 hours. Finally, one day later, the third LOI burn put the spacecraft into its 118-min, 100 ± 20 km altitude, nearly circular, polar mapping orbit. Prospector was then reoriented to its mapping attitude, its spin rate was adjusted to 12 rpm, and the nominal 1-year mapping mission began. If, as expected, fuel remains after the end of the nominal mission, a 6-month extended mission will be conducted with emphasis on high-resolution gravity, magnetic, and NS mapping.

The spatial resolution of the Prospector spectrometers is 150 km at the nominal mapping altitude of 100 km but will be improved by

lowering the altitude in the extended mission. Because gamma-ray, neutron, and alpha-particle fluxes from the Moon are very low, long integration times are required to obtain statistically meaningful data. Nevertheless, the neutron data will indicate if water ice is present in the outer 50 cm of the polar lunar regolith within several weeks after Lunar Prospector achieves its mapping orbit.

Surface Compositional Mapping

Global mapping by the GRS and NS will determine surface concentrations of key elements (Fe, Ti, U, Th, K, O, Si, H, and perhaps, Mg, Al, and Ca), which, when combined with models of lunar differentiation, will impose significant new constraints on the lunar bulk composition. They will specifically constrain the refractory element content of the surface as needed to address further the long-standing issue of whether the Moon is enriched in refractories (e.g., *Taylor and Esat* [1996]).

A determination of lunar surface composition variability will significantly improve our understanding of the evolution of the highland crust as well as of the duration and extent of basaltic volcanism. For example, one important component of lunar rocks whose abundance will be reasonably mapped is KREEP (K-potassium, Rare Earth Elements, and Phosphorus). KREEP is enriched in incompatible elements—including Th, which may serve as a KREEP surrogate—and therefore, probably represents the last crystallization product of the putative lunar magma ocean. From limited Apollo data, it is known that the distribution of KREEP is highly variable. There is evidence that KREEP contaminated most lunar magmas as they made their way to the surface from sources in the mantle or lower crust [*Binder*, 1982]. Major basin excavations and lateral variations of crustal composition may also have contributed substantially to the distribution of KREEP at the surface. Thus KREEP is a tracer for understanding the effects of volcanism and impact excavation/deposition on the crust.

The Prospector GRS is, as a function of energy, 2–8 times more sensitive than the Apollo GRS but several times less sensitive than a high-resolution germanium spectrometer. It should provide maps that can distinguish distinct surface compositional units of U, Th, and K in less than 2 months; Ti in about 3 months; Fe, Al, and solar wind-implanted H in about 6 months; O in about 9 months; Si in about 1 year; Mg in about 1.2 years; and Ca in about 1.8 years.

Finally, maps of elemental composition will determine if significant quantities of water ice exist in permanently shadowed areas near the lunar poles (as conjectured by, e.g., *Arnold* [1979]). Although returned samples show that the Moon is essentially devoid of intrinsic

A. B. Binder, Lunar Research Institute, Gilroy, CA 95020; W. C. Feldman, Los Alamos National Laboratory, MS D466, Los Alamos, NM 87545; G. S. Hubbard, NASA Ames Research Center, MS 244-14, Moffett Field, CA 94035; A. S. Konopliv, Jet Propulsion Laboratory, MS 301-125J, California Institute of Technology, Pasadena, CA 91109-8099; R. P. Lin, Space Science Laboratory, University of California, Berkeley, CA 94720-7450; M. H. Acuna, Code 695, Goddard Space Flight Center, Greenbelt, MD 20771; L. L. Hood, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

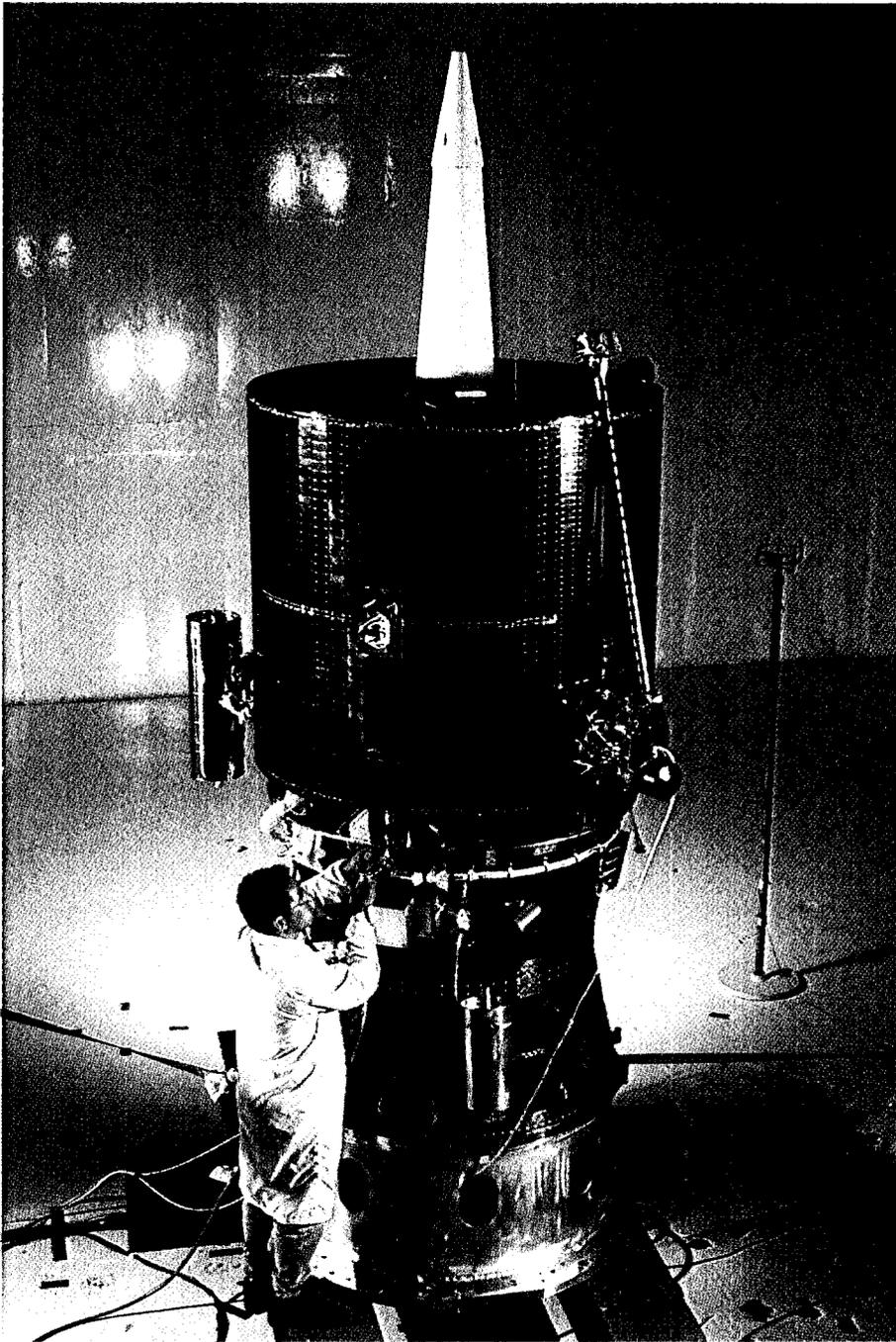


Fig. 1. The Lunar Prospector spacecraft mounted on its Star 37 Translunar Injection stage as seen in the acoustic test chamber at the Lockheed Martin facilities in Sunnyvale, Calif.

water, history shows that cometary and carbonaceous chondrite meteorite impacts have brought water to the Moon. Clementine observations indicate that permanently shadowed regions do exist and may contain significant quantities of water ice [Nozette, *et al.*, 1996]—though the latter conclusion is disputed on the basis of groundbased radar observations.

Gravity Mapping

The DGE will provide high-resolution measurements of the crustal gravity field across the lunar near side, long-wavelength gravity anomalies over the entire Moon, and further constraints on the lunar moment of inertia. Because of the low altitude and polar orbit, the

Prospector measurements will represent a significant improvement over those obtained during the Apollo program or with Clementine. Specifically, Prospector is expected to improve the resolution of the entire near side of the Moon, including polar regions, to about degree and order 90 (that is, 2° or 60 km surface resolution).

The lunar gravity field will be determined by two-way coherent Doppler tracking of the spacecraft acquired at the Deep Space Network complexes in Goldstone, California; Madrid, Spain; and Canberra, Australia. Although there is no direct tracking of the lunar farside, long wavelength gravity information will be improved, especially for the higher latitudes of the far side. High-resolution mapping of the lunar farside will have to wait for a future mission with direct observation using two spacecraft or an on-board gradiometer on a single spacecraft. With topography, the gravity field allows one to probe the interior structure of the Moon, although nonuniquely. With additional constraints, this can lead to an understanding of lunar tectonic and thermal evolution.

Based on the Apollo and Lunar Orbiter data, lunar gravity models with resolution of as much as degree and order 60 have been constructed (e.g., Konopliv *et al.* [1993]). The Clementine mission, with a laser altimeter, significantly improved what we know about the topography of the Moon [Smith *et al.*, 1996]. The improved lunar gravity field derived from Lunar Prospector data will allow, in conjunction with Clementine topography, for better selenophysical modeling of the Moon. Studies that will benefit from the better gravity models include crustal thickness investigations, which are important when addressing such issues as nearside-farside lunar dichotomy, as well as long-wavelength compensation studies. The higher resolution of the gravity field will be useful in short wavelength studies of lithospheric support as well as studies involving lunar mascons. Since Prospector is a simple, spin-stabilized spacecraft that requires minimal propulsive maneuvers, it will provide a valuable data set for investigating long-term effects of the gravity field for mission planning and science. As a precursor, it will determine the fuel costs for any lunar mission that follows, such as the proposed Japanese SELENE mission (see NASDA Report 64, Oct. 1997; <http://www.nasda.go.jp>).

All of the historical Doppler tracking data (including Clementine) will be combined with the Prospector data into a global spherical harmonic solution of at least degree and order 60. This solution will be made available to the scientific community one month after launch. The coefficients, full covariance, and corresponding maps will be archived at the Geosciences Node of the Planetary Data System in St. Louis, Mo. (see <http://wwwpds.wustl.com>).

Magnetic Mapping

The MAG/ER will provide global measurements of lunar crustal magnetic fields and will attempt to measure the lunar-induced magnetic dipole moment. A major purpose of these measurements is to investigate the existence and size of a possible lunar metallic core. The core size and mass represent basic constraints on lunar bulk composition and, hence, lunar origin models [LExSWG, 1992]. One indirect approach toward confirming the existence of a core involves studies of lunar crustal paleomagnetism. If the observed magnetization can be shown to be the result of a former core dynamo, then the existence of a core would be assured.

Current assessments, based on limited Apollo data, disagree on whether lunar paleomagnetism was caused by a former core dynamo magnetic field or by transient fields generated by local surface processes such as impacts, or both (for reviews, see Fuller and Cisowski [1987]; Hood [1995]). To better constrain the origin of lunar paleomagnetism, crustal field mapping by the Prospector MAG and ER instruments will: (1) determine the global locations, strengths, and orientations of crustal magnetic fields; (2) identify the relationships between these magnetic fields and surface features including lunar impact basins, primary and secondary basin ejecta, impact craters, rilles, and the swirl-like albedo markings of the Reiner Gamma class; (3) determine if there is a correlation between strong magnetic anomalies, swirl-like albedo markings, and H^3He concentrations; and (4) determine through analysis of inferred directions of magnetization and correlations with surface features whether the magnetizing field was an early global dipole field, or transient fields generated in impacts, or a field generated by some other process.

Among direct physical techniques for detecting a lunar metallic core, seismic methods are preferred, but the limited Apollo seismic network obtained only inconclusive evidence of a core. An alternate approach uses data from a single orbiting magnetometer to measure the lunar-induced magnetic dipole moment in the geomagnetic tail lobes [Russell et al., 1981]. This approach requires an accurate measurement of the induced magnetic dipole moment after sudden exposure of the Moon to a spatially uniform magnetic field in a quasi-vac-

uum environment (that is, at times when the Moon is in a lobe of the geomagnetic tail). Because of the high temperature of the interior and the minimal free iron content of the crust, the induced moment is then due almost entirely to electrical currents flowing in the lunar mantle and core that oppose any external magnetic field change. After a period of the order of a few hours following an external magnetic field change, induced currents in the mantle will have decayed and the residual moment will result from currents flowing on the surface of the core. Assuming that a lunar core exists and that the amplitude of the induced moment is known, it is possible to estimate the radius of the core.

Outgassing Site Mapping

Using radioactive radon and polonium as tracers, the Apollo 15 and 16 orbital alpha-particle experiments obtained evidence for the release of gases at several sites, especially in the Aristarchus region [Gorenstein and Bjorkholm, 1972]. Aristarchus crater had been studied by ground-based observers as a site of transient optical events. The Apollo 17 surface mass spectrometer showed that ^{40}Ar is released from the lunar interior every few months, apparently in concert with some of the shallow moonquakes that are believed to be of tectonic origin.

The latter tectonic events could be associated with very young scarps identified in the lunar highlands and believed to indicate continued global contraction. Thus, one goal of the APS observations is to determine whether at least some outgassing sites correlate with locations of recent tectonic activity. Because the youngest observed scarps may indicate continued global contraction, these observations will further constrain the lunar thermal history as well as sources of the Moon's surface-boundary exosphere. Finally, the data should provide information about the locations of potential sources of N_2 , CO_2 , and CO for lunar utilization. The APS will map the distribution and temporal variability of outgassing sites on the Moon. The resulting data will determine the rate and temporal variability of at least one major source of the tenuous lunar atmosphere (for a review, see Hunten and Sprague [1997]) and could have significant resource applications as well.

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