Brent Archinal/U. S. Geological Survey
Lunar Precision Geodesy: Registration and Enabling the Use of Lunar Reconnaissance Orbiter Datasets for Scientific and Operational Purposes

The LRO mission will collect enormous amounts of lunar data. I propose to conduct critical research and analyses that will allow the LRO datasets to be properly geodetically registered to each other and to the fundamental lunar laser ranging (LLR) based lunar reference frame, thus converting these datasets to much more useful information that can be used for scientific and operational exploration of the Moon. The proper registration - or control - of these massive datasets will allow them to be used in conjunction with and in comparison with each other, at the full resolution of the datasets, and similarly in conjunction with and in comparison with earlier and later lunar datasets. It is my understanding that these types of activities are not currently budgeted for or even planned as part of the LRO mission, yet they will be critical in allowing for full utilization of the data.

I propose to perform several related functions in concert with the LRO Science Team. This includes the following two primary items:

- Measuring the geometric boresights and timing offsets between instruments and their changes. This step is critical to assuring these datasets can be compared to each other at their full resolution, and is an especially critical need for the LOLA and LROC NAC data.

- Creating an initial set of LROC NAC derived landing site scale digital elevation models (DEM), at the Apollo 15 or another such site at least. This step is ABSOLUTELY CRITICAL to the LRO mission and for the establishment of future lunar coordinate frames as it will allow for the proper rotation of the final LOLA dataset into the fundamental LLR reference frame. Comparison to our existing DEMs will also serve as check on the relative accuracy of the LOLA data over the areas of the DEMs, and serve to densify the LOLA coverage in areas otherwise lacking such coverage (near spacecraft artifacts). I will assist the LROC team in checking the geometric quality of the two line scanner NAC cameras and their relative geometric position, by comparison with Apollo and other DEM information.

It also includes the following four secondary items:
- Assisting the LROC team in scheduling coverage, particularly stereo, of sites of interest.

- Advising the LROC team on the possibility of controlling their data to the MOLA and LLR reference frames.

- Assisting the LROC team in comparisons with Apollo images for change detection purposes to determine the historical cratering rate.

- Assisting all of the LRO instrument teams with information on lunar coordinate systems and standards and formats for data products.

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Joshua Bandfield/University of Washington

Characterization of lunar thermophysical and spectral properties with the Diviner radiometer

We propose to investigate the temperature and spectral behavior of the lunar surface to better characterize and isolate compositional and thermophysical units and properties. The proposed work involves three main tasks:

1) Investigation of spectral and thermophysical co-dependencies: The effective emissivity and the Christiansen frequency of surfaces in a vacuum environment can be highly variable. Anisothermal effects will also affect the apparent emissivity of a surface. Conversely, effective emissivity effects can influence the determination of surface thermophysical properties, such as rock abundance. The drifting local time of the initial year of the LRO observations will allow for the magnitude of these effects to be characterized and isolated.

2) Characterization of subsurface layering properties and rock abundance: Both layering and rocks have a significant influence on lunar thermophysical properties and surface temperatures. The variety of local time and wavelength observations to be collected by Diviner will allow for the characterization and separation of these properties.

3) Collection and investigation of emission phase function (EPF) measurements: EPF measurements allow for the derivation of sub-pixel surface properties such as rock abundance and surface slope characteristics. In addition, the multiple measurements allow for a better characterization of rock and regolith thermophysical properties. EPF observations may also be used to derive visible and thermal infrared wavelength spectral phase function properties for a better understanding of observations of other solar system objects.

The Diviner Lunar Radiometer Experiment is well suited for the activities described here. In addition, these tasks are complementary to the stated activities of the Diviner investigation team. The high quality of Diviner observations and data will allow for a much improved characterization of the thermophysical and multispectral properties of the lunar surface. Laboratory experiments and theoretical models indicate that the Diviner measurements will be rich in compositional and thermophysical information that can provide clues about the formation and development history of the Moon.
Olivier Barnouin-Jha/Johns Hopkins University Applied Physics Lab
Measuring the surface roughness of the Moon and the topographic shape of impact craters.

Much of what is known on the surface roughness of the Moon, and the topographic shapes of its impact craters, including their diameter to depth relationship is derived from extensive analyzes of Lunar Orbiter images in the mid to late 1970s. The powerful combination of LRO multi-beam laser altimeter (LOLA) with the high resolution imager (LROC) can be used to re-examine the surface roughness and the crater dimensions in a possibly more accurate, and certainly in a more detailed manner than was possible before. These new data will provide new insights on roughness scales at least at the size of a possible future landing site. In addition, new views on the emplacement dynamics of ejecta on the Moon may be derived. I propose to use my experience as a participant on the NEAR Laser Rangefinder team, the Hayabusa LIDAR team, and the Mercury Laser Altimetry team to evaluate and possibly improve the co-alignment between LROC and LOLA. With these improvements, we can generate accurate topographic profiles using LOLA within LROC images, and provide precise estimates of cross-over locations which can be tested against other efforts using least squares to identify and minimize radius and slope differences at crossovers. From these data, we estimate fractal roughness and measure crater shapes including their diameter, depth, ejecta decay rates of various craters, while tracking a variety of morphological attributes of the surface and craters, including factors that may influence crater shapes. The generated data products will also be useful for the combined photoclinometry and stereogrammetry efforts planned by LROC, providing long wavelength controls for elevation, and small scale elevations averaged over the size of the LOLA field of view.

James Bell/Cornell University
Mineralogic and Morphologic Analyses of the Moon During LRO Operations

We propose to participate in the collection, reduction, calibration, archiving, and initial scientific analysis of data to be obtained by the LROC camera on the Lunar Reconnaissance Orbiter mission. Our primary objectives are:

(1) To assist the LROC PI and team during the Exploration Mission phase of the Project in the development and operation of an automated software "pipeline" to provide efficient reduction, calibration, and archiving of LROC multispectral images. Hubble Space Telescope (HST), Clementine, and ground based telescopic data sets will be used as reference and validation points for the calibration process, where appropriate and feasible. Our extensive experience with calibration of HST, MRO/MARCI, and other spacecraft multispectral data sets will facilitate re-use of previously developed data reduction and calibration software and algorithms, minimizing the time and effort required for the development and implementation of the LROC calibration pipeline. We would also continue to assist with refinement and validation of the pipeline during the Science Mission phase of the Project.

(2) To perform a study of selected lunar dark mantle deposits during the nominal Exploration Mission's 50 km polar mapping orbit. The goals of this study would focus
on (a) mapping the composition and mineralogy of these deposits to characterize lunar surface surface and subsurface regolith properties; and (b) constraining the current small body impactor flux at the Moon by searching for and mapping the distribution of small craters that may have penetrated the thin dark mantle deposits and which thus may have enhanced constrast and visibility.

(3) To perform a search for and study of small-scale highlands scarps during the Science Mission phase of the Project, during a requested period of low-orbit, low-Sun (high incidence angle) imaging required to maximize the detectability of such low-relief topographic features. Searching for and mapping such low-amplitude features would be used to test hypotheses related to several different models of lunar formation.

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**Ross Beyer/NASA Ames Research Center**  
**Lunar stratigraphy and topography investigations with LRO**

The PI proposes to join the Lunar Reconnaissance Orbiter Camera (LROC) team to help fulfill the Lunar Reconnaissance Orbiter's (LRO's) exploration and science goals of providing high resolution imaging and topography, and assessing features for landing sites. This proposal will help achieve these goals in two major ways: (1) during the exploration phase of the mission, PI Beyer will help with planning stereo observations and building topographic models from stereo data, as well as applying his point photoclinometry technique to LROC images in order to help determine meter and sub-meter scale hazards for landing sites, and (2) PI Beyer's science investigation will examine lunar rilles and massifs which expose meter-scale lunar stratigraphy in order to learn about the detailed geologic history of the Moon, integrating data from both LROC and LOLA. The PI's presence on the science team will help assure acquisition of observations which will be important for fulfilling the goals of this investigation and the LRO mission as a whole.

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**Lynn Carter/Smithsonian Institution**  
**Radar polarimetric studies of the lunar poles and lunar pyroclastic deposits**

The Lunar Reconnaissance Orbiter (LRO) mini-RF radar is an S-band (12 cm) and X-band (4 cm) radar capable of measuring the full polarization state of the received echoes. The major purpose of the instrument is to provide a technology demonstration and to search for ice at the lunar poles; however, this polarimetric data will also be very useful for studies of lunar geology and surface physical properties. This proposal outlines a plan to use the polarimetric capabilities of mini-RF to study lunar pyroclastic deposits (including Aristarchus, Orientale and Oppenheimer) and the polar regolith. Surface models can be used to compute dielectric constants, estimate mantling deposit depths, and map changes in rock abundance and surface vs. subsurface scattering across an area. The mini-RF images will be compared to available optical and infrared imagery, as well as to lower resolution ground-based radar images at P-band (70 cm) and S-band (13 cm), to give context to the narrow, but high-resolution, mini-RF strips. This work is relevant to NASA's goal to understand the evolution and history of the Moon. It is also relevant to NASA's lunar exploration goals, since both the poles and pyroclastic deposits have been
suggested as possible sites of future landed missions. As a participating scientist on the LRO mission, I will assist with development of software for data processing and analysis, targeting of observations, data analysis and publication, and archiving of the results.

Thomas Duxbury/Jet Propulsion Laboratory
Lunar Local and Global Cartography and Calibration

As a Lunar Reconnaissance Orbiter (LRO) Participating Scientist (PS), I will serve as members of the LRO Science Team and will participate in LRO Science Team activities including mission and observation planning, data analysis, archiving, and publication.

My efforts will support the goals of the Vision for Space Exploration and the robotic Lunar Reconnaissance Orbiter (LRO) mission by enabling future human exploration and providing excellent opportunities for future science missions. I will use the data from LRO containing detailed information about the lunar environment. Data from the multiple LRO payload instruments and one technology demonstration will provide key data sets to enable humans to return to Mars. My specific scientific objectives for LRO are to support:
1. the production of the first highly accurate 3D lunar cartographic maps
2. the registration / cross correlation of the different payload instrument data to the precision 3D cartographic maps to map mineralogy across the whole Moon; and
3. the assessment of features for landing sites.

To meet my specific scientific objectives, I would use data from the following instruments:
1. Lunar Radiometer Experiment (DIVINER) to map the temperature of the lunar surface at 300 meter horizontal scales;
2. Lunar Orbiter Laser Altimeter (LOLA) to provide a precise global lunar topographic model and geodetic grid, enabling precise targeting, safe landing, and surface mobility, and to characterize the polar illumination environment by imaging permanently shadowed polar regions of Mars;
3. Lunar Reconnaissance Orbiter Camera (LROC) to acquire images to assess <1 m scale features to facilitate safety analysis for potential lunar landing sites and to identify regions of permanent shadow and illumination; and
4. Mini Radio-Frequency Technology Demonstration (Mini-RF) technical demonstration using its synthetic aperture radar (SAR) imaging modes as most relevant to my scientific and exploratory roles as a PS on LRO.

My experience to perform these same function on MGS, Odyssey, MRO and the ESA Mars Express missions will be used together with my existing stereo photogrammetric software using laser / imaging / SAR data. Experience as a Science Team member on Clementine will be directly applicable to lunar science.
Richard Elphic/NASA Ames Research Center  
Synthesis of LRO and Other Data to Characterize the Physical Properties of Lunar Cold Traps

We propose to analyze data from LRO to establish the location and physical properties of lunar polar cold traps, particularly the abundance and state of hydrogen there. To accomplish this, we will analyze and cross-correlate data from several LRO instruments, together with relevant data from Lunar Prospector. The goal is to create the highest-possible spatial resolution maps of the location and extent, temperature, and hydrogen abundance within permanently-shadowed regions (PSRs) as well as nearly-permanently-shadowed regions (near-PSRs) that are cold but which receive occasional sunlight. We will accomplish this by applying an advanced image reconstruction technique [Elphic et al. 2007] to the LRO and LP neutron data. In this technique, LRO topography, permanent shadow and surface temperature maps place constraints on neutron data to determine how much hydrogen/water ice is present, where it is located and what is its likely physical form (e.g., ice vs. implanted solar wind H). In principle the result would be hydrogen abundance maps with resolution approaching a few km or less, much better than any neutron instrument alone. The activity will span both the exploration and science mission phases, and will make use of the nominal LRO orbit and operations.

Objectives:
We will analyze and cross-correlate data from several LRO instruments, namely DIVINER, LAMP, LEND, LOLA, LROC and Mini-RF to define likely locations and characteristics of potential polar cold traps. Other relevant lunar data, such as the Lunar Prospector Neutron Spectrometer data, will be incorporated as well. While each dataset has its limitations, together they provide a superset of information that will help us to determine the physical properties of, and constrain the abundance and spatial extent of hydrogenous materials within, the Moon’s polar regions.

Lisa Gaddis/U.S. Geological Survey  
Geologic Analyses of Historic and LRO Data of Lunar Volcanic Terrains

The primary objective of this Lunar Reconnaissance Orbiter (LRO) Participating Scientist proposal is to contribute to the successful acquisition and analysis of data from the LRO mission. This proposal includes two major tasks (one scientific research and one in support of science analysis of LRO data during exploration) and focuses on integration of previously acquired lunar image data and high resolution, meter-scale images and elevation models from the LRO Camera (LROC) and other LRO instruments. The science goal is to use historic and new lunar data to study major volcanic landforms on the Moon to address fundamental questions about their character and formation. The exploration goal is to support crater flux estimates of the Moon by the LROC science team during by incorporating Lunar Orbiter digital data into a data framework for searching for craters that have formed since 1966 and 1967. This proposal addresses three of the major goals of the LRO mission, including landing site identification, assessment of potential lunar resources, and characterization of current impact hazards. Results of these studies with integrated historic and LRO data will help us to understand volcanic and/or impact processes on the Moon that concentrate and distribute important
chemical elements such as titanium and iron that may provide resources for to support future human exploration and habitation. The resulting increased knowledge of lunar evolution and geologic processes forms the basis for understanding such processes on other terrestrial planets in the Solar System.

William Garry/Center for Earth and Planetary Studies

Analysis of the Morphology and Emplacement of Volcanic Features on the Moon with the Lunar Reconnaissance Orbiter

This proposal outlines an investigation of channeled lava flows and rilles using the Lunar Reconnaissance Orbiter Camera (LROC) and the Lunar Orbiter Laser Altimeter (LOLA) on the Lunar Reconnaissance Orbiter (LRO) satellite. Volcanic rilles, which appear to be carved into the landscape, and channeled lava flows, which have thick flow margins and leveed-channels, have played an important role in the formation of the lunar maria. Lunar rilles are common in the maria, but identifiable flow margins of channeled lava flows are scarce. Why does it appear that rille formation is preferred to lava flows with thick margins on the Moon? LRO can provide the necessary data to better understand differences and similarities in the formation of these volcanic features through morphologic analysis and mathematical modeling. The best developed channeled lava flows on the Moon occur in Mare Imbrium where a flow field extends from the southwest for over 1600 km towards Sinus Iridum. One of the largest lunar rilles, Vallis Schröteri, is located in one of the most geologically diverse locations, Aristarchus plateau, on the outskirts of Oceanus Procellarum. This project will focus on these two prominent lunar landforms with the following objectives: I. Analyze the morphology of the Mare Imbrium lava flows and qualitatively and quantitatively explain the emplacement parameters necessary to form the extensive flow field. II. Reassess the geologic processes involved in the formation of Vallis Schröteri through analysis of the topography and morphology. III. Compare the morphology and emplacement processes of lunar rilles and lava flows to analogues on Earth, Mars, and Venus. Morphologic analysis will be completed through mapping the study areas using LROC wide-angle camera images and detailed observations of the channels, flow margins, and rille interior with LROC narrow-angle cameras (NAC). Flow dimensions will be obtained from topographic cross-sections created from LOLA data. Mathematical models commonly used in the literature and more recently developed models will be used to calculate emplacement parameters (i.e. effusion rate). Analogue studies will be based on previous and current work by the PI and published studies by others. LRO will reveal unprecedented details of the lunar surface from orbit which warrants a re-evaluation of these features. For example, the Phase I flows in Mare Imbrium are currently mapped based on color differences from the surrounding material, but LOLA could reveal subtleties of the flow front topography that has not been previously recognized. The origin of Vallis Schröteri is still debated. LROC NAC images of the cobra head crater, the inner rille, and basalt outcrops along the upper rille wall at Vallis Schröteri will allow for observations of morphologic details that could change current interpretations about its formation. This project will provide insight into the emplacement of lunar channeled lava flows and rilles.
Rebecca Ghent/University of Toronto
Thermophysical properties of fine-grained ejecta haloes from LRO Diviner radiometer observations

Recent work using Earth-based radar measurements has shown that large impacts on the Moon produce a distinct facies of highly comminuted ejecta depleted in fragments >10 cm in diameter. These fine ejecta form concentric radar-dark haloes around their source craters, representing a mantling layer on the order of 10m thick. By comparison with similar ejecta haloes surrounding Martian impact craters, we conclude a) that the comminution process and ballistic emplacement of ejecta on the two planets occur in similar ways, and do not depend on gravity or target properties; and b) it is very likely that like the Martian case, the lunar crater haloes also have a thin mantling layer of very fine particles, which cannot be detected using Earth-based radar. The LRO Diviner experiment will allow detection of the finest fraction of this population. Integration of Diviner thermal IR observations with radar observations will result in a deeper understanding of particular physical properties of lunar ejecta than has been possible to date. This characterization is important because it will contribute to our understanding of the physics of cratering and ejecta emplacement, to constraining the physical environment at the surface for purposes of hazard mapping, and to understanding how the regolith evolves.

The objectives of the work proposed here are:
1) To use LRO Diviner lunar radiometer nighttime temperatures and derived thermal inertia to determine the thermophysical properties of fine-grained ejecta haloes associated with lunar impact craters, in order to constrain their surface physical properties (i.e., particle size distributions); and

2) To integrate these observations with observations of the same features using Earth-based radar imagery, in order to characterize the physical makeup of the top several meters of continuous ejecta blankets in greater detail than has previously been possible.

As a participating member of the LRO team, I will produce a database of crater ejecta haloes and their thermal and derived physical properties. Derived mineralogies calculated by other members of the LRO team will be included, as available. Access to a searchable database of crater ejecta halo properties will increase the ease and efficiency with which workers investigating crater ejecta can utilize new LRO Diviner results.

Jeffrey Gillis-Davis/University of Hawaii, Manoa
Assessment of Lunar Resources: Using Targeted Observations of Mini-RF in Conjunction with Data from LROC, LEND, DLRE, LOLA, and LAMP.

Integrating information from the Lunar Reconnaissance Orbiter Camera (LROC), the Lunar Exploration Neutron Detector (LEND), Diviner Lunar Radiometer Experiment (DLRE), Lunar Orbiter Laser Altimeter (LOLA), Lyman-Alpha Mapping Project (LAMP), and Mini Radio-Frequency (Mini-RF) will provide an unprecedented
comprehensive understanding of the lunar regolith. Unlike the other instruments, however, Mini-RF is not intended to acquire a global data set. In fact, the nominal schedule of operation is to collect data only over the lunar Polar Regions, polarward of 80 degrees latitude. Data rate, ~2 Gbits per minute, is the factor preventing Mini-RF from collecting a global data set. Thus, we propose creating a list of geologic targets of interest where Mini-RF, S-band and X-band radar data can contribute valuable information for accurate determination of regolith composition and structure.

The composition and structure of the lunar regolith are of fundamental importance to the geologic study of, and sustained presence on the Moon. Mini-RF data can provide insight into the structure and composition of the upper 1-10 m of the lunar regolith, which, in conjunction with data from LROC, LEND, DLRE, and LAMP, can provide an accurate assessment of resources (i.e., ilmenite and 3He) and estimates of rock population within pyroclastic deposits. Both spectral data and radar data sense regolith composition but observe different depths below the surface. Integrating complimentary information from these two independent data sets provide the possibility of correcting errors in ultraviolet-visible (UVVIS) spectral based maps of TiO2 that arise from regolith constituents other than ilmenite (e.g., TiO2 in silicates, nanophase iron, crater ray contamination). Targets of particular interest are basalt flows that spectral reflectance based algorithms estimate as high-TiO2 compositions but measure as low TiO2 compositions as determined from Lunar Prospector neutron data. Accurate ilmenite distribution maps are essential for using ilmenite and 3He, a solar wind gas that is preferentially trapped in ilmenite grains, as lunar resources. In addition, targeting areas of known and potential pyroclastic deposits will provide a measure of pyroclastic rock population. Mapping particle size distribution within pyroclastic deposits is beneficial from a resource standpoint (i.e., needing to mine relatively low rock populations pyroclastics), and from a science perspective (i.e., high rock populations would be valuable for looking for pyroclastic deposits that contain potential mantle nodules).

If radar data for geologic targets of interest are not acquired while the Lunar Reconnaissance Orbiter (LRO) mission is active, then the opportunity to measure these features is lost. In addition, as Mini-RF is a technology demonstration, the data it gathers for various geologic targets will help to assess the capabilities of the miniaturized radar instrument, identify potential next generation modifications, and evaluate applicability of studying lunar geology with radar.

Timothy Glotch/Stony Brook University
Compositional Variability of the Lunar Surface from the Diviner Lunar Radiance Experiment and the Lunar Reconnaissance Orbiter Camera

The goals of the proposal are to map the silicate and oxide mineralogy of the Moon and to assess the extent of space weathering on the both the lunar highlands and maria. Compositional mapping will be done primarily using the Diviner’s three narrow band channels placed near the region of the silicate Christiansen feature, supplemented by its four broadband thermal channels which are placed at longer wavelengths. This compositional mapping will be correlated with LROC multispectral observations, which
will be capable of mapping the distribution of oxide minerals - particularly ilmenite - and olivine. In addition, the UVVIS channels on LROC are well-placed to assess the magnitude of space weathering on the lunar surface.

Diviner is expected to make high temperature (> 300K) mineralogical measurements of 70% of the lunar surface from the equator to 70 degrees latitude. Current plans call for using bands A3-A5 to map the position of the Christiansen frequency, which should provide a rough indication of silicate composition. In addition to these three narrow band filters, there are four broadband filters which occur at 12.5-25, 25-50, 50-100, and 100-200 μm. The filter functions of these channels can be used to calculate an average emissivity from each filter, effectively making Diviner a 7-band mineralogical instrument rather than a 3-band instrument. Although the three longest wavelength broadband filters occur on a different focal plane than the rest of the filters, precise geometry of each observation provided by the Diviner science team will allow for band-to-band registration.

Many minerals have spectral features in the regions represented by the broadband filters, although few measurements of relevant materials have been made longward of 50 μm. A prime added value of this proposal will be to provide a spectral library of these materials out to 200 μm. These spectra will be acquired at Stony Brook University. In addition to the Diviner mineralogical measurements, LROC multispectral observations will be highly useful for determining the presence of ilmenite, olivine, and perhaps other minerals. The UVVIS filters are particularly well suited to study the extent of space weathering on differing lunar surfaces. It has been shown that space weathering, likely due to the presence of nanophase iron, produces a strong blue slope that is most evident in the 300-400 nm region.

Thus, using observations from both Diviner and LROC, this proposed work would (1) increase the capabilities of Diviner by effectively making it a useful 7-band mineralogical instrument, (2) correlate mineralogical measurements made by Diviner and LROC to maximize the mineralogical science return of each instrument, and (3) use LROC multispectral observations to assess the extent of space weathering on the lunar surface and understand its correlation with age and silicate and oxide mineralogy.

Bernard Hawke/University of Hawaii

An Investigation of Lunar Dark Mantle Deposits Using LROC Data

The objective of the proposed work is to assist the Lunar Reconnaissance Orbiter Science team in the planning of observations, calibration, archiving, and scientific analysis of data from the LRO Camera instruments with a focus on using LROC data to investigate regional dark mantle deposits of pyroclastic origin. Regional pyroclastic deposits are of high scientific interest and are considered to be strong candidates as sites for lunar outposts because of their resource potential and site safety considerations. As an LRO Participating Scientist, I would utilize data from the LRO Camera to conduct geologic and compositional studies of regional dark mantle deposits of pyroclastic origin in order to assess their potential for in-situ resource utilization, to evaluate their suitability as landing sites for future robotic and human missions to the lunar surface, and to answer important scientific questions concerning explosive volcanism on the Moon. The work will initially focus on the seven major regional pyroclastic deposits on the lunar nearside.
that are currently thought to have the greatest resource potential and scientific interest. LRO Camera images will be used to produce a number of data products including geologic and compositional maps. These data products and LROC multispectral images will be utilized to answer important scientific questions concerning the composition, homogeneity and mode of emplacement of each regional pyroclastic unit. The resource potential of the regional pyroclastic deposits will be evaluated using LRO Camera images and the derived data products. Candidate landing sites will be identified at the various regional pyroclastic deposits. Each potential landing site will be intensively investigated using LRO Camera images as well as data from other LRO instruments (LOLA, DLRE) as they become available.

Amanda Hendrix/JPL/CalTech
Investigation into Lunar Surface Composition and Weathering Effects

I propose to contribute to the Lunar Reconnaissance Orbiter mission as a participating scientist based on my robust experience in ultraviolet spectroscopy of surfaces and in particular far-UV water ice detection and modeling, and based on my interest to investigate the lunar surface composition and weathering effects through UV spectroscopy. My strong background in UV spectroscopy of surfaces, especially from the Galileo and Cassini missions, will be an asset to the LRO mission.

I propose to use the LAMP instrument to map out the lunar surface during the science phase of the mission to study composition and understand space weathering effects on different terrains of differing mineralogies. Species of interest on the Moon, such as ilmenite, are spectrally distinctive in the FUV and thus FUV data can be used to map out abundances of such species. As such, this proposal is distinct from currently-planned LAMP objectives and also complements LROC goals. My previous studies have investigated space weathering effects in lunar samples and on asteroids at UV wavelengths and have shown that the UV wavelength range is particularly sensitive to monitoring the effects of space weathering. In probing and mapping the composition of the lunar surface, it is vital to understand the effects of weathering in order to determine the true nature of the lunar surface.

Additionally, I am actively working on modeling FUV spectra of icy surfaces as measured by the Cassini Ultraviolet Imaging Spectrograph (UVIS), work that is directly applicable to analysis of LAMP data. As such, my input, experience and models would be a valuable resource to the LAMP team.

Laszlo Keszthelyi/United States Geological Survey
Flow on the Moon:
A Stepping Stone to Mars and Beyond

Science Task 1: Investigate flood lavas on the moon. Recent studies have fundamentally revised our understanding of flood lava flows. I propose to use LROC imagery (and LOLA topography) to investigate the emplacement of the lunar maria via the distribution
of impact small craters and topographic features. This will have profound implications for the plumbing system and magma source region. Also, the lava morphology affects the nature of the local lunar regolith, an important consideration for landing sites on the maria.

Science Task 2: Compare channels on the Moon and Mars. Sinuous rilles were carved by lava. However, very similar features on Mars are purportedly carved by water. Learning to remotely distinguish between water and lava carved channels will be essential for future missions to Mars.

Operations Task 1: Assist in optimizing targeting procedures, especially for stereo imaging. My experience with Galileo, MER, and MRO, can be helpful in balancing the use of software to automatically plan a sequence versus the need for humans to be “in the loop” for decisions that require scientific insight.

Operations Task 2: Geometric and radiometric calibration. I have experience with determining the mounting of HiRISE on the MRO spacecraft and am adjusting the radiometric calibration parameters provided by MSSS for the CTX camera. I propose to assist in similar work for the LROC NA camera.

Operations Task 3: Liaison to other U.S. Geological Survey LRO support operations. The USGS is developing image processing software for LROC. Furthermore, the expertise of the USGS cartographers and photogrammetrists will assuredly be called upon to support landing site evaluations. Having science team members in Flagstaff can greatly facilitate these kinds of activities. The PI has been working in this role for the HiRISE team and proposes to do the same for LROC.

Rongxing (Ron) Li/The Ohio State University
Integration of Lunar Reconnaissance Orbiter Camera (LROC) and Lunar Orbiter Laser Altimeter (LOLA) Data for Near Real-time Precision Lunar Topographic Mapping and Landing Sites Assessment

In this Lunar Reconnaissance Orbiter (LRO) Participating Scientists (PS) project, we propose to integrate Lunar Reconnaissance Orbiter Camera (LROC) with Lunar Orbiter Laser Altimeter (LOLA) data to provide the first high-accuracy 3D lunar cartographic maps along with an assessment of potential landing sites for future lunar landed missions at a high level of precision (submeter). The proposed near real-time system will be developed based on our Mars orbital and Earth satellite data processing system developed at OSU. It will strictly model the imaging geometries of the LROC NAC and WAC sensors and integrate LROC images with LOLA data along with image and LIDAR data from previous lunar missions in order to achieve the best possible accuracy for topographic mapping. The developed system has the flexibility of multi sensor and multimission data integration, as well as near real-time mapping capability. Thus, the mission can be supported by fast product turn around time, quick responses, timely make-up data acquisition, and other time dependent operations.
Project objectives include:
1) To develop a strict 3D stereo photogrammetric model for LROC imagery based on push-broom and frame imaging principles,
2) To develop a method for combined bundle adjustment of LROC and LOLA data to improve the absolute accuracy of LROC images by incorporating LOLA data as absolute ground control,
3) To develop innovative methodology to integrate LROC imagery and LOLA data in order to produce the highest level of resolution and the most comprehensive data set that will include highly accurate 3D topographic terrain models, orthophotos, and 3D surface feature measurements, and
4) To apply the developed model and methods to support candidate site assessment for future lunar landing and enable high precision in scientific investigations during mission operations.

The developed methods and techniques will contribute to the advancement of the science and technology of planetary mapping. During LRO mission operations, the topographic products generated in this project will directly contribute to assessment and selection of potential landing sites for future landed mission. The multi-mission data integration capability enables cross-mission image correlation that will be very valuable for various scientific investigations during LRO’s science mission and beyond.

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Paul Lucey/University of Hawaii
LRO Mission Participation: Mineral Mapping With Diviner and LOLA

This Participating Scientist project will use data collected by LRO’s instrument complement to produce maps of key lunar minerals that are central to addressing lunar science issues, in particular the distribution and abundance of mafic rock types in the lunar highlands. The two instruments used for this project are LOLA and Diviner. LOLA is not commonly thought to be a mineralogic sensor, but its data can be used to map the relative abundance of low-calcium pyroxene via detection of changes in spectral reflectance with temperature. Diviner's three multispectral bands near 9 microns are well positioned to detect and discriminate the Christensen Frequency of the mixtures of olivine, feldspar and pyroxene that dominate lunar compositions.

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Timothy McClanahan/NASA Goddard Space Flight Center
Enhancement of Lunar Exploration Neutron Detector (LEND) Mission Operations and Science Return

This proposal defines and elaborates several novel methods and applications that will optimize the mission operations and science return for the Lunar Reconnaissance Orbiter (LRO). Scope of efforts and methods discussed in this proposal are primarily focused on the Lunar Exploration Neutron Detector (LEND) system, but are applicable to other LRO instrument systems e.g., LAMP. The overall significance of these contributions will justify the selection of Timothy Patrick McClanahan (NASA GSFC) as a participating scientist with the Lunar Reconnaissance Orbiter, Lunar Exploring Neutron Detector...
The proposal time frame over which my services are best utilized is before and during the exploration portion of the mission. In that time frame adoption of these methods will enhance the scientific value of science data products by optimizing coverage and enhancing the quality and rate science data products can be generated. These products will also facilitate cross instrument analysis through the ability to rapidly generate model specific data products.

In this period my ground and signal processing expertise and experience with Lunar Prospector Neutron Spectrometer data, Mars Odyssey High Energy Neutron Data (MO-HEND) and projected LEND mission ephemeris can facilitate development of appropriate mission systems that will enhance mission planning and the overall quality and rate that LEND science products can be derived. The proposal will specifically address five key elements that will define my unique contributions and involvement with the LEND science team. Elements 1-4 will define unique software systems that I will enhance or develop that will be required to realize several mission and science optimizations. Element 5) will address my proposed involvement with the science team.

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**Jürgen Oberst/German Aerospace Center (DLR)**

**Studies in Lunar Geodesy and Cartography**

We propose to provide technical mission support for LRO and to carry out a comprehensive analysis program for the Laser Altimeter (LOLA) data that will be of interest to LRO engineers, planetary explorers, and Lunar scientists alike. We shall focus on the problem of vertical and lateral alignment of the LOLA data with the Lunar-fixed coordinate system. Comparisons will be made between features seen in the images of the camera and topographic patterns in the altimeter profiles. The Apollo landing sites, with the precisely known coordinates of the Laser retroreflectors, are important reference areas. Another goal of our proposed study is to map lunar surface roughness for investigations into surface maturity and assessment of landing site safety. We will use the spreading of the returning laser pulse as an indicator for roughness, which will allow us to map surface roughness at uniquely small scale, within the size of the laser footprint. Studies of laser pulse characteristics will also be used for calibration of laser beam divergence and laser spot size on the ground.

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**Timothy Stubbs/NASA Goddard Space Flight Center**

**Mapping Lunar Surface Electric Fields and Characterizing the Exospheric Dust Environment**

The Moon is electrostatically charged by the surrounding plasma environment and solar ultraviolet (UV), which results in the formation of strong local electric fields at the surface. There is evidence that these electric fields drive the transport of charged lunar dust, especially around the terminator and the polar regions. Lunar surface charging and dust transport processes are poorly characterized and understood, and will likely pose a hazard to human and robotic explorers. The objectives of this proposal are:
(1) to map lunar surface electric fields using the topographic and shadowing data acquired by LOLA and LROC during the exploration phase as inputs into lunar surface charging models - with emphasis on the lunar poles and permanently shadowed regions (PSRs). This will help identify regions that are hazardous due to strong local surface electric fields.

(2) characterize the distribution of lunar exospheric dust using limb-scanning observations with the LROC (visible/UV), LAMP (UV) and possibly Diviner (infra-red) instruments during the science phase. These observations will then be compared with dust transport and light scattering models in order to determine the source and dynamics of the exospheric dust.

(3) to predict the extent of triboelectric charging of dust on the surface using the temperature data provided by Diviner, which will help determine where dust transport is most active.

(4) to analyze and interpret any CRaTER signals generated by exospheric dust impacts (secondary science goal). If dust is detected, this will be an important tool for characterizing exospheric dust.

Achieving these objectives will require working closely with the LRO science and instruments teams, and necessitates involvement with science phase planning. The results of this research are time critical since they will have significant implications for many other lunar science and exploration activities.

The environment at the lunar poles is practically unexplored, so it is vital that it be well characterized and understood before a manned lunar outpost is established near the South Pole Aiken Basin, as is currently planned. The work described in this proposal represents a critical step in the characterization the lunar dust-plasma environment and the development of a predictive capability.

The characterization and understanding of the lunar dust-plasma environment has been identified by the Science Plan for NASA/SMD, the NASA Advisory Council, and the National Research Council as being of critical importance to both science and exploration on the Moon. This proposal is highly relevant to NASA's strategic objectives, and will greatly augment the scope of the science and exploration return from the LRO mission.

Thomas Watters/Smithsonian Institution
Tectonism on the Moon: Global Characterization and Analysis of Lunar Faults

The proposal describes a program of study using data returned by instruments on the Lunar Reconnaissance Orbiter (LRO). LRO will provide the opportunity to characterize in unprecedented detail known large-scale tectonic landforms and, for the first time, identify small-scale tectonic features only resolved in the limited highest resolution images of the Moon. As a LRO participating scientist, my primary objective will be to take a lead role in the identification, characterization, mapping, and analysis of tectonic
landforms on the Moon using images obtained from the Lunar Reconnaissance Orbiter Camera (LROC), and topographic data obtained from the Lunar Orbiter Laser Altimeter (LOLA) and from LROC stereo imaging. A comprehensive database of lunar tectonic features that includes location, orientation, and length will be compiled using LROC regional and global mosaics. Tectonism on the nearside is largely confined to the mare basins and adjacent highlands. This basin-localized tectonism is expressed by two landforms, wrinkle ridges and rilles or troughs; these are the surface expressions of crustal shortening and extension. Lobate scarps are another significant tectonic landform on the Moon. Lunar lobate scarps, while analogous in morphology to their planetary counterparts on Mercury and Mars, are much smaller in scale. They are the dominant tectonic feature on the farside. However, because of their small scale, lunar lobate scarps can only been identified in the highest resolution Apollo and Lunar Orbiter images. Another remarkable aspect of the lobate scarps is their age; they may be the youngest endogenic features on the Moon. As a LRO Participating Scientist, I will assist in generating high-resolution stereo derived topography and other special data products. I will contribute to the calibration of LROC images, using those obtained for ground-based and inflight calibration, and to high-resolution image targeting. I will also contribute to many aspects of the geologic and geophysical analysis of Moon. I will directly participate in the E/PO effort using the resources of the National Air and Space Museum and the Smithsonian Institution to educate the public about the Moon using data returned by LRO.

Michael Wyatt/Brown University
Mapping Silicate Variations on the Moon with the Diviner Lunar Radiometer Experiment (DLRE) and Cross-Comparisons with other Compositional Approaches

The objectives of the proposed research are to identify and map lunar surface lithologies at global to local spatial scales to better constrain the origin and evolution of the crust through geologic time. This will be accomplished using mid-infrared spectral data from the Lunar Reconnaissance Orbiter (LRO) Diviner Lunar Radiometer Experiment (DLRE) in three complementary research paths.

1) Classification of lunar surface lithologies by identifying and mapping the spectral diversity of the mid-infrared emissivity maximum (Christiansen Feature) and comparing results to existing and newly-acquired mid-infrared laboratory spectral data of lunar surface materials.

2) Integration of the Diviner derived datasets with other compositional remote-sensing approaches (visible/near-infrared and gamma-ray spectroscopy) to further constrain the origin and evolution of lunar surface materials.

3) Combine Diviner, Lunar Orbiter Laser Altimeter (LOLA), and Lunar Reconnaissance Orbiter Camera (LROC) datasets to investigate the extent of subsurface compositional diversity in lunar impact craters.
Cross-correlations between techniques are critical for developing a complete understanding of lunar surface materials. The proposed research plan is designed to make each task complementary to the others and provides the opportunity to integrate the DIVINER dataset with laboratory spectral data and other remote-sensing approaches. This work will thus enable us to map variations in silicate mineralogy across the entire lunar surface and classify and interpret lunar lithologies.

Cary Zeitlin/Southwest Research Institute
Comparison of Lunar and Martian Radiation Environments

Both the continuous radiation from the Galactic Cosmic Rays and the sporadic radiation from Solar Particle Events are of interest both scientifically and as a matter of practical concern for astronauts on long-duration missions to the Moon or beyond. We propose to assist the CRaTER team with data analysis, computer modeling, and creation of a new data product for inclusion in NASA's Planetary Data System. The new data product and the emphasis of the data analysis will be comparisons with similar data obtained by instruments aboard the 2001 Mars Odyssey spacecraft in orbit at Mars.

Analysis and modeling of the data are necessary to fully understand the radiation environment in lunar orbit. Dr. Zeitlin has extensive experience with similar particle detection systems, data analysis methods for both flight data and data obtained with beams at particle accelerators. He is familiar with two large and complex computer codes that are needed for modeling.

The proposed work will be done using established, PC-based methods of data analysis and simulation. Standard data analysis tools include the Fortran and C programming languages, the FLUKA Monte Carlo simulation code (publicly available via the European Center for Nuclear Research, CERN), and the PHITS Monte Carlo simulation code (also publicly available via Dr. K. Niita of the Research Organization for Science and Technology of Japan).

Results from CRaTER, and specifically the comparisons to be made with data from Mars Odyssey, will be useful to heliospheric scientists interested in modeling the propagation of solar disturbances through the inner solar system. The results will also be of great interest to NASA's Space Radiation Health Program, which is both legally and ethically obliged to keep the radiation exposure of crew members as low as reasonably achievable.