Planetary Data Archiving, Restoration, and Tools
Abstracts of selected proposals
(NNH15ZDA001N-PDART15_2)

Below are the abstracts of proposals selected for funding for the Planetary Data Archiving, Restoration, and Tools program. Principal Investigator (PI) name, institution, and proposal title are also included. 97 proposals were received in response to this opportunity. On December 14, 2015, 24 proposals were selected for funding.

Robert Anderson/Jet Propulsion Laboratory
Conversion of Seven Completed Maps into ArcGIS for Publication

Seven completed USGS geologic quadrangles for Mars (Central and Southeast Argyre Planitia and East Acidalia Planitia/West Deuteronilus Mensae) previously funded by the Planetary Geology and Geophysics program (PGG) and awarded to Dr. Tim Parker at JPL have been compiled in various formats (chiefly Canvas for MacOS and Photoshop) that need to be converted into ArcGIS for final map publication. Dr. Parker completed each of these maps in these earlier graphics programs prior to the USGS switch to standard ArcGIS format and change from the old Viking Orbiter base map to the new Themis daytime IR global mosaic using the Mars 2000 areocentric East longitude coordinate system. Because funding was exhausted in completing the maps, and no additional funding was requested to transfer the mapping to the new base maps, final review and publication of these maps are currently on hold. With the recent interest by NASA and from J. Skinner at the USGS to get all previously awarded maps either completed or returned to the queue for reassignment, we have a strong desire (along with J. Skinner concurrence) to get these maps transferred into ArcGIS and published and made available to the science community. We believe that it would be an inefficient use of NASA funds to reassign these maps to new PI's when there is minimal additional work needed to transfer the maps into ArcGIS format and get them into publication. In this proposal, we are asking for minimal funds to complete the process of converting Dr. Parker's seven USGS quadrangles into required ArcGIS format. The majority of the funds we are requesting are to support Mr. Jeff Schroeder, an ArcGIS specialist here at JPL, who will convert the maps into ArcGIS format and work in conjunction with USGS to get all maps into final production. Minimal funds are requested by the PI (Anderson) who will oversee the project and assure the all maps are completed on time and within budget, and by Co-I (Parker) who ensure that all the important units are carried over correctly from the old to the new maps and to work with Co-I (Schroeder) to correct any problems with the unit boundaries that may arise due to converting the old maps to the new base map projection.

This project will provide comprehensive, detailed geologic maps of the geology of the SE Argyre Planitia, East Acidalia Plantia/West Deuteronilus Mensae regions of Mars. Project results directly address the PDART program goals of providing high order data products for the community and the advancement of our understanding of the geologic and tectonic histories of aqueous sedimentation in Argyre and the northern plains on Mars.

Peter Bernath/Old Dominion University
Absorption Cross Sections for the Outer Planets

The goal of this proposal is the laboratory infrared spectroscopy of molecules of importance in the atmospheres of Titan and the Giant Planets as well as comets. Of particular interest are the hydrocarbons ethane, propane and propene. We will deliver to the Atmospheres node of NASA's Planetary Data System (PDS) high resolution infrared absorption cross sections for these species in the infrared and near infrared for an appropriate set of temperatures, pressures and compositions to match typical planetary atmospheric conditions. PDS has agreed to accept and archive our data. We will measure the absorption spectra of cold hydrocarbon gases broadened by hydrogen and nitrogen with a high resolution Fourier transform spectrometer. Many of these spectra will be recorded at synchrotron facilities in Australia and Canada as well as at Old Dominion University. These spectra will be converted into sets of absorption cross sections. These cross sections are needed for reliable retrievals of trace gas concentrations and physical properties. The proposal contributes to the Planetary Data Archiving, Restoration, and Tools (PDART) program by: "1.5 Generation of New Reference Information". Included in this category are: "Proposals to make laboratory measurements, conduct experiments, or otherwise generate new reference information that is intended for general use in planetary science will be considered. Examples may include, but are by no means limited to, spectral data..." Our laboratory spectral data is needed for example to support Cassini observations of Titan, Saturn and Jupiter as well as measurements made with ground-based and space-based telescopes of the outer planets and their satellites.

Michael Bland/USGS Flagstaff
Relative Accuracy Assessment and Technique Improvements for Digital Elevation Models in the Outer Solar System

Fully elucidating the geologic history of a planetary surface requires complete characterization of the three-dimensional shape of the terrain. Robust topographic information permits the measurement of crater depths and fault-scarp heights, the evaluation of local and regional slopes, and the identification of subtle landforms like flexural troughs and long-wavelength folds. Each of these features can then be used to constrain the tectonic and thermal evolution of the body. In the inner Solar System, laser altimeter or radar data often provides robust surface heights, and permits Digital Elevations Models (DEMs; also Digital Terrain Models, DTMs) generated from image data to be confidently tied to ground. In the outer Solar System, however, altimeter data generally does not exist, and DEMs produced for those bodies have greater degrees of uncertainty both in absolute and relative height determination. Here we propose to systematically and quantitatively assess both the quality and variability, including a complete characterization of uncertainties, of DEMs produced for the outer Solar System

using different techniques. Additionally, a revised standard operating procedure (SOP) and recommended best practices will be developed to assist the planetary community in producing their own DEMs.

We will address these objectives by: 1) Generating DEMs using both the commercial software SOCET SET® (a manual method) and the Ames Stereo Pipeline (an automated method); 2) Quantitatively and qualitatively assessing the quality of each individual DEM; 3) Comparing the DEM results generated across both methods, and by different processors, to understand the source of differences in the final DEM products;
4) Producing an SOP for generating DEMs for the outer Solar System (i.e., in the absence of a ground) using SOCET SET®, which will help to standardize the procedure and enable the community to produce consistent, repeatable DEMs with high accuracy;
5) Publicly releasing all data products through the NASA Planetary Data System (PDS), archive all developed software through NASA's GitHub repository, and communicate our results to the planetary science community through presentations at professional meetings and by publishing two peer-reviewed journal articles.

The proposed work is explicitly relevant to PDART, as we will "generate higher-order data products" by producing DEMs using Galileo data. The effort to standardize the procedure for generating DEMs for outer planet satellite datasets (or any dataset that does not have coincident altimetry data) will enable the planetary community to generate DEMs of higher, more consistent quality, and better quantify the uncertainties in the resulting elevation values. These results will significantly "increase the quality of digital information and data products available for planetary science research and exploration", which is a fundamental goal of the PDART program. We will also produce tools, through an improved SOP, that will "enable and enhance future scientific investigations." This proposed work does not focus on scientific investigations and no data analysis will be performed in the completion of this work other than to validate the accuracy of the DEMs generated. Assessing the quality and variability of DEMs for the outer Solar System, independent of any science objectives, is long overdue, and is precisely the type of investigation that the PDART program enables.

David Blewett/Johns Hopkins University Applied Physics Laboratory
Optical Constants of Opaque Minerals: A Case Study with Ilmenite

Science Goals and Objectives: Opaque minerals are important constituents of planetary regoliths, from sulfide minerals that may be present on Mercury, to the ilmenite ($FeTiO_3$) in lunar mare basalts, to carbonaceous phases in low-albedo asteroids. In order to use radiative-transfer models to analyze the reflectance spectra of assemblages containing these phases, the optical constants (i.e., the complex refractive indices, with real (n) and imaginary (k) parts) must be available. Methods exist to determine optical constants of metallic phases (like iron) and transparent phases like silicates. However, determination of the optical constants of opaque phases has traditionally been a challenge. We will use a novel technique that determines the complex refractive indices of ilmenite from a suite of

existing RELAB reflectance spectra (0.3-2.6 ?m). First, we will conduct a proof-of-concept study designed to demonstrate that our method is viable for use on low-reflectance phases. We will use our technique to derive the optical constants of magnetite, a low-reflectance opaque that is similar to ilmenite. We will then compare our magnetite (n, k) to previously reported values. Assuming our technique/approach successfully yields results similar to those previously reported for magnetite, we will move on to ilmenite. Otherwise, we will write up our findings and conclude the project at this stage. If the magnetite proof-of-concept is successful, we will carry out the analysis to derive the complex refractive indices for ilmenite. We will validate our ilmenite (n, k) values by modeling RELAB spectra for several synthetic and natural mixtures that contain known ilmenite abundances. The technique that we develop and validate in this project will provide data that will allow improved derivation of composition from remote observations of a variety of low-albedo planetary surfaces that contain opaque phases. We will archive our optical constant values in the NASA Planetary Data System, and we have obtained a letter of support from the manager of the PDS Geosciences Node.

Methodology: Our approach for determining optical constants combines two techniques. The first [1] relies upon Hapke's formalisms [e.g., 2] to derive the imaginary index of refraction, k, by minimizing the difference between the observed and calculated reflectance spectrum. Multiple particle size fractions of the same material are used to independently derive k, and then these results are compared with each other to create a final k-spectrum. The second technique uses a variation of Kramers-Kronig analysis [2], known as subtractive Kramers-Kronig analysis (SKK). This method is used to derive the real index of refraction, n, from k [e.g. 3].

Relevance: The proposed effort will generate new reference information, and as such is relevant to the stated scope of PDART: "Proposals to ...generate new reference information that is intended for general use in planetary science will be considered. Examples may include ...optical constants." Our work will enable improved mapping of ilmenite/TiO_2 abundance in the lunar maria, and will pave the way for determination of n and k for other opaque phases relevant to Mercury, asteroids, and other bodies.

References: [1] R.N. Clark and T.L. Roush (1984), J. Geophys. Res. 89, 6329.
[2] B. Hapke (2012), Theory of Reflectance and Emittance Spectroscopy, 2nd ed., Cambridge. [3] S. G. Warren (1984), Appl. Opt. 23, 1206.

Thomas Duxbury/George Mason University
Mariner 69 Image / SPICE Restoration, Catalog and Archive

To directly respond to the PDART solicitation, this proposal would generate higher-order Mariner 1969 far and near encounter data products, archive and restore these image and associated NAIF SPICE kernel / data sets and products, create new searchable reference databases, and generate new reference information. This would make the Mariner 1969 data readily available and increase the amount and quality of digital information and data

products available for planetary science research and exploration. This proposal only includes a small amount of data analysis and interpretation, sufficient to validate the generated products. This proposal does not contain any hypothesis-based science. These data products would be made available to the scientific community through peer review and then archive and distribution by the NASA Planetary Data System (PDS) Geosciences Node and the Navigation Ancillary Information Facility (NAIF) Node. The restored and derived bundle archive would have a very positive impact on future planetary science research and exploration by converting the existing but nearly unusable archive to current and readily useable archival standards employed within the planetary science community. These would provide a broad scale record of Mars surface albedo and clouds from over 40 years ago and would extend the precision spacecraft-based astrometric observation of Phobos and Deimos by two years, increasing the precision of the secular accelerations for orbit evolution.

Cynthia Evans/NASA Johnson Space Center
Creating and Serving Novel Data Products of Astromaterials: Combining Image-Based 3D Reconstructions and X-Ray CT Data of Astromaterials to Enable Targeted Scientific Research and Enhance Public Access to Astromaterials Collections

Science Goals and Objectives
We will enhance curation protocols and documentation strategies for current and future astromaterials collections by providing new data sets that combine 3D reconstructions of astromaterials samples from high-resolution precision photography (HRPP) and X-ray computed tomography (XCT) to produce Virtual Extraterrestrial Samples, or VES. We have developed and tested preliminary protocols for this documentation technique and created interactive 3D models of lunar and meteorite samples that will be served to researchers and the public. Although the lunar samples were extensively photographed when first received in the 1960s-70s, the images are not sufficient to create 3D reconstructions - a state-of-the-art practice in documentation today. Since many Apollo samples have been heavily sectioned, the ability to create 3D reconstructions of the original surfaces of these important samples has been lost. Thus, there is a critical need to update documentation protocols in order to serve higher-order contemporary data sets of astromaterials collections. This new image data will increase accessibility of sample data, enhance scientific investigations and targeted sample requests, and provide a new visual platform for the public to experience and interact with the samples.

Methodology
A multidisciplinary team with expertise in conservation practices, professional photography, photogrammetry, imaging science, geoscience and astromaterials curation has collaborated to investigate non-destructive documentation methods for preservation of NASA's astromaterials, performing initial tests on lunar and meteorite samples. A comprehensive set of HRPP are taken and subsequently processed in 3D reconstruction software to create an accurate image-based 3D exterior model of each sample. Our initial

image-based 3D model has a resolution of 60 microns, and we have identified refinements that can double this resolution. On the same samples, XCT data are collected and 3D models created, providing a volumetric data set of internal composition. We successfully correlated exterior and interior 3D models, showing how valuable the two data sets are in tandem. The fusion of the HRPP and XCT data sets to create VES presents challenges, and methods are in development to co-register the data and provide web-based tools to explore these samples interactively. Our protocol development has the specific goals of refining our imaging procedures, developing the co-registration system for the two data sets, developing a system for distributing the data on the Astromaterials Curation database, and archiving the data in PDS compliant format.

Relevance to Planetary Data Archive and Restoration Tools
These combined data will provide unprecedented access to physical and inferred compositional information on a subset of complex lunar and meteorite samples, creating higher-order data products that meet the rigor of current research demands. Our feasibility studies illustrate that this non-destructive documentation technique is operationally possible and functionally beneficial. Initial results show clearly that the combined HRPP data and XCT data are crucial in a comprehensive contemporary conservation protocol that allows surface and interior information of the complete sample to be archived for posterity, served to the public for education and outreach, and be used by scientists as a preliminary research tool. This technique has great potential for development, may be applied as preliminary examination protocols for future sample return missions, and will enable targeted and collaborative research by multiple investigators simultaneously.

Corey Fortezzo/United States Geological Survey
Digital Renovation of the 1:5,000,000-Scale Lunar Geologic Maps as a Seamless Global Product

In 2013, we completed an initial digital renovation of the six 1:5,000,000-scale lunar geologic maps (near, central far, east, west, north, and south sides). This renovation allows the geologic maps to be overlain on newer, higher resolution datasets including the Lunar Reconnaissance Orbiter Camera Wide Angle Camera mosaic and the Lunar Orbiter Laser Altimeter digital terrain model. The renovations involved redrafting the line work from the previously published maps, with only minor reinterpretations.

We propose a two-year project to stitch together the six digitally renovated geologic maps to create a globally consistent, 1:5,000,000-scale geology and timeline derived from these older, but still relevant maps. The goal of this project is to make resource for the community to use for science research and analysis, for future geologic mapping efforts, be it local-, regional-, or global-scale products, and as a resource for the general public interested in lunar geology.

This product is relevant to goals and objectives of NASA and PDART as it would "generate higher-order data products...", "...restore data sets or products, and generate new reference information...". This proposal does not represent hypothesis-based science but would "...increase the amount and quality of digital information and data products available for planetary science research and exploration, and produce tools that would enable or enhance future scientific investigations". The data product will be hosted on the established Imaging Node Annex service, and available, without permission, to anyone who would like to use the lunar data.

Perry Gerakines/NASA Goddard Space Flight Center
Extending the Range of Calibrated Infrared Spectra for NASA Planetary Science Missions

Spectra of the surfaces of astronomical objects in the Solar System can be observed both telescopically and through fly-by and orbiter missions. Examples include recent work with the Cassini orbiter and the Hubble and Spitzer Space Telescopes as well as the anticipated observations by the James Webb Space Telescope (JWST) and the New Horizons mission. The interpretation and quantification of all such observational data requires a substantial library of laboratory work, an area to which our research group has long contributed.

Here we propose to build on our recent experiences in recording calibrated solid-phase spectra of icy compounds from about 10 to 150 K. Our recent work has focused on the 5000 - 400 cm-1 (2.0 - 25 µm) mid-infrared region (e.g., Hudson et al., Icarus, 2014; Moore et al., ApJSS, 2011) producing the first consistent sets of optical constants (n and k) of amorphous and crystalline hydrocarbon ices, as well as absolute band strengths, all in electronic form and posted on our group's web pages. We now propose to extend the range of our measurements to include the weaker IR features of interest in the near-IR (8000 - 5000 cm-1, 1.25 - 2.0 µm) and far-IR (400 - 30 cm-1, 25 - 333 µm) regions. To assist us we recently purchased a new Thermo Nicolet spectrometer that covers all three spectral regions of interest. We also now are measuring ice densities directly with a new quartz-crystal microbalance, to produce a significant improvement over published IR band strengths. Moreover, all spectral measurements will be made at higher resolution and sensitivity, and at more temperatures, than now available in the literature. All results will be freely available in digital format on our laboratory's website and will be submitted to the Planetary Data System (PDS). Our new near-IR results will be of value for studying, for example, icy worlds with HST, JWST, and New Horizons, while our new far-IR results will be applicable to Cassini, archival data from Herschel, and future far-IR telescopes.

The proposed work is relevant to the Planetary Data Archiving, Restoration, and Tools Program as it consists of "laboratory measurements" that will "generate new reference information that is intended for general use in planetary science". In this case, our results

will make a significant contribution to the available data used for the interpretation of the reflectance spectra of icy satellites and TNOs.

Iouli Gordon/Smithsonian Astrophysical Observatory
Expanding Capabilities of the HITRAN and HITEMP Spectral Databases for Planetary Research

The application of high-resolution spectroscopy is a powerful tool for understanding the chemical abundance of constituents in planetary atmospheres, as well as determining their various physical conditions. In fact, even interpretation of low-resolution spectra from distant planets requires band models which are built from high-resolution line-by-line reference spectra. All of the existing NASA planetary missions equipped with spectrometers of any resolution use band models or radiative-transfer codes that are based on the HITRAN spectroscopic database that we have developed and maintained for over 40 years. However, for most of this time, funding of the HITRAN database was directed at interpretation and modeling of the terrestrial atmosphere (i.e. limited to the gases that are dominant absorbers in the terrestrial atmosphere, at atmospheric temperatures, and assuming air as the perturbing gas). The peer-reviewed articles on HITRAN are the most cited in the Geosciences. The situation changed in the last five years when we succeeded in obtaining funding from the NASA PATM program to extend the capabilities of the HITRAN database towards planetary studies. That funding has insured some major accomplishments in this area. We have released the HITEMP2010 database which contains a significantly larger extent of data for the H2O, CO2, CO, OH and NO molecules than is currently given in HITRAN. This allows modeling and interpreting spectra of hot atmospheres. We have added new bands and improved the quality and extent of available bands for many HITRAN gases relevant to planetary atmospheres. We added C4H2, HC3N, CS, H2 and SO3 to the molecules already available in HITRAN. We have also calculated partition functions for many species of planetary importance. In addition, we have added files of collision-induced absorption (CIA) data for many collisional partners. Finally, the database has been restructured into flexible SQL format allowing dynamic use of new parameters such as broadening and shifting of spectral lines by He, H2 and CO2. A new web interface (www.hitran.org) and an Application Programming Interface to conveniently work with data have also been created. All of these efforts are extremely relevant to proper simulation and characterization of planetary atmospheres. The goal of our proposal is to build on the success of our current PATM grant devoted to validated compilations of spectroscopic parameters for the molecules relevant to planetary atmospheres research. We see PDART as a crucial program to continue our efforts.

We propose to: 1) Further develop the HITRAN and HITEMP databases by improving the quality of current parameters and by adding i) new molecular species for which there has been a breakthrough in the quality of ab initio calculations; ii) parameters for foreign gas broadening parameters for the molecules of planetary interest; iii) new molecular

species that are required for planetary research (examples include SO, SiO, C3H4 and many others) and 2) new significant isotopologues for the existing molecular linelists.

The tasks will include: 1) Collection and evaluation of existing data in the literature (both experimental and theoretical). We emphasize that data validation is a very important part of the HITRAN philosophy. It includes cross comparisons of existing data, checking for basic selection rules, and validation against independent raw laboratory and field spectra.

2) Compiling the datasets into accepted formats. HITRAN has a traditional well-known ASCII format, but since we will be adding new parameters we will consult with the planetary community about enabling other well-defined formats. This can be done quite easily thanks to the new SQL structure of www.hitran.org. In fact we now provide features that allow users to create their own formats if they wish.

3) Providing support to the users. We have a long and successful tradition in this area, and plan to expand to include webinars, etc.

Liming Li/University of Houston
Generating and Archiving Cassini ISS Long-Term Multi-Filter Global Maps for Jupiter and Saturn

Compared to the archived global maps of terrestrial bodies, global maps of gas giant planets are not archived well. The Imaging Science Subsystem (ISS) cameras onboard the Cassini spacecraft have collected images of Jupiter and Saturn at different wavelengths since 2000. In this proposal, we use the public ISS data sets in the Planetary Data System to process and archive multi-filter (200-1100 nm) global maps of Jupiter (2000-2001) and Saturn (2004-2014) at spatial scales from ~ 50 km/pixel to ~ 500 km/pixel. The Cassini ISS has 12 filters ranging from ultraviolet (200 nm) to near infrared (1100 nm). We will not only process and archive global maps for each available filter but will also make colorful global maps by combining maps at different visible filters. In addition, we will process and archive the backplanes and calibration for the ISS images to further facilitate scientific studies.

The software to make global maps of Jupiter and Saturn with Cassini ISS images has already been developed and tested by the proposal team (section 1.3.2). The proposal team is comprised of an ISS team member, an ISS data expert, an ISS participating scientist, and an ISS team associate, who together have extensive experience with ISS data processing (section 1.7). The proposal team also includes experts in data archiving/analyzing and imaging of giant planets. Some encouraging results generated by the software are shown in this proposal (section 1.3.3), which suggest that the proposed global maps will be promising and quite fruitful.

The global maps of Jupiter and Saturn at different wavelengths will benefit the community of planetary science by facilitating the studies of the atmospheric systems at

the global scale (e.g., banded structures, clouds, aerosols, winds, vortices, waves, turbulence, albedo, and radiant energy budget). In addition, the long-term global maps of Saturn (2004-2014) will advance our exploration of the seasonal changes of Saturn's global atmosphere, which is one of main scientific objectives of the Cassini extended Equinox and Solstice missions. Finally, the proposed global maps of Jupiter, taken at a range of wavelengths corresponding to different pressure levels in Jupiter's upper atmosphere, will serve as historical datasets to benefit ongoing and future missions (section 1.2).

The proposed effort of making global maps of Jupiter and Saturn matches the scope of the PDART program because it involves the processing and archiving of higher order data products from a planetary mission - Cassini.

Jay McMahon/University of Colorado
Small Bodies Geophysical Analysis Tool

Interest in small bodies in the solar system continues to grow as more information is obtained about these bodies through missions and from new observations. Current missions to small bodies involving close orbits and observation and interaction with the surfaces include Dawn, OSIRIS-REx, Rosetta, and Hayabusa 2. The recent focus by NASA on the Asteroid Redirect Mission indicates that missions to small bodies will continue in the near future. Furthermore increased observations focused on small bodies in the near-Earth, main belt, and outer solar system regimes continue to provide new information about small body populations. The combination of all these aspects shows there is a high level of interest in small bodies in the solar system.

In studies of small bodies, the shape of the body is of fundamental importance in terms of understanding the history, evolution, and dynamics of the body itself, as well as in trying to interact with the body in robotic or manned missions. Scientific analyses are interested in predicting the YORP evolution and on shorter timescales modeling the spin dynamics which depend on the mass properties of the body. Mission designers are similarly interested in the possible spin dynamics, but also need to model the gravity field and surface accelerations and slopes for landing operations. All of these examples intrinsically depend on the shape of the small body in question.

This proposal seeks to build a comprehensive tool to analyze the geophysical properties of small solar system bodies. The basis of this analysis is the shape model of the body. The main purpose of this tool will be to compute the variety of geophysical parameters which engineers and scientists use for their analyses. The list of possible outputs includes the gravity field, surface accelerations, surface slopes, dynamic equilibria in the body-fixed frame, YORP coefficients, mass properties, and observational predictions.

The tool will allow the user to load already existing shape models, or to build an artificial shape from scratch. In either case, one of the main features of this tool will be the ability

to modify a shape model through a graphical user interface. Examples of this include: dragging selected vertices from the shape model to modified positions; adding extra vertices to allow for higher resolution modeling in desired regions; adding or modifying surface features like boulders and craters, etc. Importantly, we will work with astronomers who produce shape models to include their modeling uncertainties to guide users of this tool to modify the features of the shape model within the constraints of observations of the body. Once a shape is modified to the user's desires, the geophysical parameters of interest will be updated accordingly, and will be output for use in external analysis processes. Furthermore artificial images, lightcurve and radar observations can be generated from a given shape model.

Ralph Milliken/Brown University
Enhancing the RELAB Spectral Database for the Modern Era of Planetary Sciences

The Reflectance Experiment LABoratory (RELAB) facility housed and operated at Brown University has amassed a significant library of visible-near infrared-infrared (VIS-NIR-IR) reflectance spectra over the last ~30 years. The current RELAB spectral database contains ~24,000 spectral files corresponding to ~12,000 unique samples, including a significant number of lunar and meteorite samples. The latter are particularly important given past, recent and upcoming missions that utilize VIS-NIR-IR wavelengths (e.g., Mars MGS, Odyssey, Mars Express, MRO, Chandrayaan-1, Dawn, Messenger, OSIRIS-REx, Hayabusa-2 etc.). All data collected at RELAB have been publicly available over this time period and available to the world. However, the needs of the scientific community to easily search and access this large database have grown tremendously during the digital age and it is necessary for the database to evolve in order to meet those needs. Here we propose several important steps to significantly increase and improve the usability and scientific impact of the vast RELAB spectral library. The work plan can be divided into three major tasks:

Task 1: Restructure existing spectral database/catalog, correct inconsistencies, and incorporate into a relational database management system to prepare for integration with an online search tool. When possible, missing sample information will be added to the database as well as auxiliary sample information (chemistry, mineralogy, photos, etc.).

Task 2: Format all existing spectral files to be in compliance with PDS4 standards and, after peer review, deliver all existing spectral data to the PDS Geosciences node (at Washington Univ. in St. Louis) for formal archiving through NASA. Our goal is to establish a system in which all future spectral data are made PDS-compliant as they are collected, ensuring simple and streamlined delivery to the PDS in future years as the database grows.

Task 3: Create a user-friendly online tool for searching the RELAB database, examining spectral plots, and downloading data as desired. Auxiliary information (e.g., chemistry, mineralogy, photos, journal references) will be included when available. The tool will

also include an online method for submitting sample measurement requests and sample information to RELAB. This tool with be made available through the PDS Geosciences Node and will be mirrored at Brown University.

The expected result of this project is a significant and necessary increase in the accessibility, usability, and visibility of the NASA RELAB spectral database. This work is relevant to the PDART call in that it focuses on archiving of spectral data and creating a tool for searching and using those data. All existing spectra and auxiliary data will be archived in the PDS (following review) at the end of the award period. We will also develop a web-based tool hosted through the PDS and mirrored at Brown that will allow users easy search and download capabilities. These activities are outside the current scope of funding for the RELAB facility and the PDS Geosciences node, and there are currently no established funds to support such work beyond responding to this PDART call.

Nicholas Moskovitz/Lowell Observatory
Development of an Observational Planning and Community-Driven Minor Planet Database

Three major databases of minor planet orbital elements are currently maintained in the United States: the Minor Planet Center (MPC) catalog, JPL Horizons, and astorb at Lowell Observatory. In spite of the wide use and importance of these databases, none of them focus on providing physical data (e.g. light curves, spectral types, albedos) beyond basic orbital elements. The vast array of physical data available in NASA's PDS and other online repositories are not well integrated or regularly updated in any of these orbital databases. Furthermore, there is no central forum for research groups to communicate and coordinate the acquisition of physical data in a timely manner.

We propose here to build a new system from the existing astorb catalog to accumulate and centralize minor planet characterization data, to provide novel observational planning tools, and to provide real-time updates using a crowdsourcing-like approach. This database and website will be useful in the coordination and prioritization of minor planet observations across multiple research groups and will be available to the public at no cost. Our team has been actively developing preliminary versions of these tools and website for the past year and have made important progress, however a significant overhaul of the backend is still required. The proposed work will accomplish this as well as providing new observing and data visualization tools for the amateur and professional research communities. These planned upgrades to astorb will allow for a sophisticated system of community interaction with the database.

This proposal is highly relevant to the PDART program. In addition to consolidating reference databases, we will develop new software tools for the community that may be used for enhanced science investigations and coordination across research groups. This system will resolve the long-standing issue of fractured observing tools and observing

campaigns, thus resulting in a more efficient, and thus more effective, observing community.

Alexey Pankine/Space Science Institute
Re-Calibration of the MGS TES Spectrometer dataset

Science Goals and Objectives.
Almost a decade after the end of the Mars Global Surveyor (MGS) mission the data collected by the Thermal Emission Spectrometer (TES) onboard MGS still constitute an invaluable source for analysis of the Martian atmosphere and surface. TES provided first multi-year global view of the Martian dust and water vapor cycles, atmospheric and surface temperatures, and provided a window into surface mineralogy. The data collected by TES are widely used in the Mars community.

The goal of the proposed study is to re-calibrate infrared spectra collected by the TES spectrometer using a more accurate calibration function. The re-calibrated spectra will be used to re-retrieve opacities of the atmospheric aerosols (dust and water ice clouds), the column abundances of the water vapor and to extend retrievals of surface mineral abundances. In addition, the TES atmospheric data products (dust and ice cloud opacities, water vapor abundances retrieved from daytime nadir observations) currently archived in the NASA Planetary Data System (PDS) will be supplemented with the data products retrieved from the nighttime and limb observations, and from observation over cold surfaces. The expanded dataset of the atmospheric data products (aerosols opacities and water vapor column abundances) will be archived in the PDS.

Methodology.
The TES spectra will be re-calibrated using new estimates of the calibration function. The PI recently completed a NASA-funded study to re-calculate the TES calibration functions utilizing long-term averages over hundreds of MGS orbits. These improved calibration functions more accurately reflect the dependence on the instrument temperature and exhibit reduced levels of the instrumental noise and of the systematic radiometric error.

Improved understanding of the nature of the radiometric error affecting TES data collected after orbit 7000 enables error correction in the nadir and limb spectra. This error correction will improve quality of the derived data products (atmospheric opacities retrieved from limb spectra and from spectra collected over cold surfaces) and will enable increasing surface coverage of the surface mineralogy retrievals. The TES atmospheric data products currently archived in the NASA PDS are limited to daytime nadir retrievals over warm surfaces (Tsurf>220 K). These data products will be re-derived with the newly recalibrated and corrected for radiometric error TES spectra. In addition, limb spectra and spectra collected over cold surface will be used to retrieve opacities of the atmospheric dust and water ice, and mixing ratios and column abundances of the water vapor, and in this way to augment the current TES PDS dataset. Retrievals of surface mineralogy will

be extended beyond the orbit 7000 and used to improve spatial coverage of the TES mineral maps.

Relevance to PDART.
The proposal is relevant to the PDART program since it will re-calibrate MGS TES spectrometer data and will generate new data products. Re-calibration falls under Data Set Restoration and Archiving activities within the scope of PDART. The new data products will include the re-calibrated (corrected) TES spectra, atmospheric data products (dust and water ice cloud opacities, water vapor column abundances) derived from these re-calibrated spectra. Additional TES data products will include nighttime and limb dust and ice cloud opacities, water vapor column abundances over cold surfaces and vertical profiles of mixing ratios from limb spectra, and surface mineralogy from MGS orbits beyond orbit 7000.

Robert Pappalardo/Jet Propulsion Laboratory
Enhancing SatStress GUI: Simplifying Stress Calculations for Satellites

Objectives: Some satellites of our solar system show distinctive evidence for tectonism. Many of the proposed sources of stress that can deform the surfaces are potentially tied to the tidal deformation the moons experience as they orbit their parent planets. Other sources of global-scale stress include volume changes induced by the melting or freezing of a subsurface layer, a change in the orbital characteristics (eccentricity and/or orbital recession or decay), a rotation of the outer part of the satellite relative to the interior (nonsynchronous rotation), a shift in the body relative to the rotation axis (polar wander), or a change in obliquity. Thus, to understand the geological history of tectonized moons, we must understand the relationship between the observed surface features and potential stress sources. Most researchers use a combination of analysis of data returned by spacecraft and computer modeling to correlate observed geological features to possible stresses that created them. For calculating stresses, a variety of individual modeling programs exist that typically assume a thin elastic shell and/or a multi-layered viscoelastic body. One such program, SatStress, was developed by Z. Selvans and described by Wahr et al. (2009); it is open-source and has been used by numerous researchers for modeling nonsynchronous and diurnal tidal stresses. However, invoking this code requires a moderate level of computer programming knowledge and significant time to get the model operational, preventing many researchers from using this publicly available resource. Kay and Kattenhorn (2010) developed a more user-friendly graphical user interface (SatStressGUI) that requires a minimal level of preexisting computer programming knowledge. However, the SatStressGUI interface is currently only rudimentary, slightly buggy, and does not yet exploit the full potential of the SatStress code.

We propose to continue to expand on the preliminary investment we already put into SatStressGUI to further improve and enhance the interface and its abilities. These improvements will be made possible through the following objectives:

Objective 1: Make SatStress and SatStressGUI more accessible to the community by making it much easier to install and use.

Objective 2: Debug and Enhance SatStressGUI to accommodate a more diverse range of stressing mechanisms, specifically: polar wander, obliquity, orbital recession/decay, and despinning.

Objective 3: Improve the user interface and create a platform that will allow users to seamlessly model stressing mechanisms and export those results to other programs such as ArcGIS.

These proposed improvements are based on specific feedback from the research community that has used SatStress and SatStressGUI. Our aim is for SatStressGUI to be an open-source that enables correlation of features observed on satellites across the solar system to potential stressing mechanisms, leading to a better understanding of their geological histories. Additionally, this program can be used to provide a baseline for researchers to test their own models against.

Mario Parente/University of Massachusetts
Denoising and Spectral Summarization of CRISM Images with Elevated Detector Noise

The increase in spatial and spectral resolution from OMEGA to CRISM led to new discoveries of water-related minerals; yet, most CRISM discoveries were made averaging tens of pixels due to the uncertainties in the spectral shapes of single pixels. While great progress in data calibration and reduction has been made in the current version (TRR3) of CRISM data and even the prototype MTRDR, challenges still remain, especially in regions of lower signal to noise and for observations performed in the last couple of years due to the aging hardware. The denoising procedures currently employed by the CRISM team in the MTRDR pipeline was designed for cubes acquired at IR detector temperatures around or below 121 K and perform satisfactorily up to 125 K. Currently the majority of the hyperspectral targeted observations have been acquired at elevated temperatures, some as high as 135 K. This issue affects over 6000 image cubes, including key areas of Mars such as Gale crater, where the MSL "Curiosity" rover is operating, together with all advanced derived data products based on such input data.

In this proposal, we focus our attention on these problematic scenarios and explore the potential of novel spectral artifact mitigation techniques that is the first step to exploiting the full CRISM inherent resolution. Spectral artifacts in CRISM images are due to residual atmospheric contributions and detector-based effects that are column-dependent and also to other spatially localized temperature-dependent effects. One denoising approach we are investigating separately addresses both sources of spectral distortions. We leverage the dependence of the column-based artifacts on the input signal levels and

the high frequency signal variations of the temperature-dependent noise. Preliminary results have shown the potential of the technique to improve the definition of spectral shapes and facilitate the identification of previously undiscovered phases in images of Gale crater and Acidalia Planitia.

A different line of investigation for denoising will aim at expanding some of techniques already implemented by the CRISM team in the existing filtering procedure, such as leveraging the correlation in the hyperspectral signal in the implementation of the filter, an approach that has already been successfully implemented for multispectral (subsampled) CRISM images.

A second goal of this proposal is to provide the community with a database of new advanced data products and algorithms for the automated identification and localization of the unique spectral signatures present in a CRISM scene. These tools and products are needed due to the volume and complexity of the CRISM dataset, which overwhelms the capacity of practitioners for manual analysis. This research will follow several paths of investigation to extract the unique spectral signatures of CRISM hyperspectral scenes, which can be used as the scene concise ground compositional representation for cataloging purposes. We believe that this work could be a promising addition to already available spectral browse products and summary parameter maps. In addition, we believe that the software tools could be beneficial to future spectroscopic instrument mission and help in the identification of selecting the most spectrally informative data products.

This proposal is relevant to the Planetary Data Archiving, Restoration, and Tools Program because it will create several products that will be made available to the planetary science community. New reference information will be provided in the form of restored data cubes and spectral summary products that will allow new investigations that would not be possible with the current available data. In addition, we will develop software tools and numerical models that will facilitate the analysis of the CRISM dataset and would enable or enhance future spectroscopic science investigations of interest to the Planetary Science Division.

Noah Petro/NASA Goddard Space Flight Center
A New Geologic Map of the Borealis Quadrangle (H-1) on Mercury

Until the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft inserted into orbit around Mercury in 2011, almost 60% of the north polar region, Borealis Quadrangle (H-1), remained imaged at illumination and viewing geometries poorly suited for morphological observations. Full image coverage of H-1 is now available, enabling the ability to create new geologic maps. Geologic maps provide a unique synthesis of the surface of a planetary body to address how geologic processes and the resulting units and features relate to each other in space and time. Geologic maps become a basis for the completion of scientific investigations of planetary surfaces, representing a fundamental tool that now requires an update for Mercury.

We propose to create a new geologic map of the Borealis Quadrangle (H-1) on Mercury at a scale of 1:5,000,000 (1:5M), following the mapping standards set by the United States Geological Survey (USGS). The primary objective of the proposed effort is to facilitate and aid future investigations related to the geology and geologic history of the north polar region of Mercury, by improving upon the original Mariner 10-based USGS geologic map (I-1660; Grolier and Boyce, 1984) and by leveraging the new global datasets obtained MESSENGER. The primary deliverable of this effort will be a Scientific Investigations Map (SIM) published through the USGS, enabling dissemination throughout the scientific community.

This mapping investigation will use only publicly accessible, PDS-released MESSENGER data to construct a geologic map of H-1 through three tasks: Geologic mapping (Task 1), Age determination (Task 2), and Map publication (Task 3). Pursuant to PDART requirements, beyond the minimal analyses required to establish geologic units, measure craters, and determine ages, no hypothesis-based science will be conducted.

This proposed H-1 quadrangle map would be the first USGS-published geologic map covering the entirety of the north polar region of Mercury. This new map will vastly improve upon the original USGS geologic map that had ~40% coverage (Grolier and Boyce, 1984), in part by filling in the unmapped region in the Mariner 10 data. The proposed map for H-1 would incorporate multiple datasets obtained by MESSENGER, in addition to synthesizing results of recent publications, to document and develop a regional stratigraphic history of the north polar region that would be useful to future scientific investigations (e.g., theoretical modeling of volcanic smooth plains emplacement, influence of pre-flooding topography on northern smooth plains boundaries, history of tectonic deformation within the northern smooth plains) and future mission planning for the European Space Agency's BepiColombo mission.

The generation of an USGS-published SIM of the Borealis Quadrangle (H-1) will enhance future scientific investigations of the north polar region on Mercury. The production of this cartographic product will generate a scientifically valuable higher-order data product, an objective of the PDART program. The new geologic map will be made available to the scientific community via the USGS Publication Warehouse, which is the sole archival vehicle for geologic maps that have completed the USGS review process.

Sylvain Piqueux/Jet Propulsion Laboratory
Improving Thermal Model Capability for the Planetary Science Community

Scientific/Technical/Management
Planetary surface temperatures are frequently measured by instruments on both landers and orbiters as a means to constrain the physical nature of near-surface regolith, which

then informs the understanding of past and present geophysical processes. Accurately understanding and interpreting the past and present geological processes that have shaped a planet is a fundamental endeavor in planetary exploration. While the availability, diversity, and potential of temperature data to solve critical scientific questions increases continuously, the use of reliable dedicated numerical tools to enable the interpretation of that data poses significant challenges to non-specialists. We propose to enhance and expand the capability of a well-established thermal model, and facilitate the access of the model code set and thermal numerical modeling tools for data analysis to the broad community. To do so, we will:

1. Generalize a well-establish numeric model of heat transfer for planetary surface (KRC) to any rotating body in the solar system;
2. Incorporate additional geophysical processes controlling surface and sub-surfaces temperatures, as well as satellites eclipses;
3. Validate, distribute, and facilitate the use of KRC by a broad community through a set of interfaces tuned to the skill level and needs of the potential user.

Methodology
Our goals and objectives will be achieved through:

1. The modification and improvement of KR's FORTRAN code base;
2. The validation of these model improvements following a rigorous methodology;
3. The archiving and distribution through established web tools;
4. The development of user-friendly tools (web-interface, precoded functions, input files, web-based documentation) facilitating the use of the model by a wide range of users.

Relevance to PDART
ROSES 2015 states that "PDART solicits research to develop or validate software tools". The PDART program "supports the development and dissemination of software tools that facilitate the use of existing datasets or that would enable or enhance future science investigations of interest to the Planetary Science Division". Thus, the proposed work is relevant to PDART as it will improve and distribute a numerical model freely accessible to the community and will provide tools to help individuals correctly utilize this model. This proposed work does not focus on scientific investigations and no data analysis will be performed. This proposed work will develop and disseminate software tools that facilitate the use of existing datasets and would enable and enhance future science investigations. The proposed work will enhance a well-established numerical model to predict planetary (sub)surface temperatures, and generate a user-friendly tool and interface facilitating the analysis of planetary surface temperatures, including (but not limited to) Mercury, the Moon, Mars, Europa, asteroids, comets, and other satellites.

Julie Rathbun/Planetary Science Institute
Active Volcanoes on Io from Ground-Based Observations of Jupiter and Mutual Satellite Occultations

Most studies of the temporal and spatial variability of Ionian volcanoes have been forced to rely exclusively on spacecraft data, primarily Galileo (Davies, et al., 2012ab; Veeder, et al., 2012; Hamilton, et al., 2013), because only spacecraft data is generally available on the PDS in physical units and with relevant location information. However, ground-based observations, while at a lower spatial resolution, give the longest temporal baseline and often the highest temporal resolution of any data set. It was, for example, only the ground-based data that allowed the discovery of the semi-periodic nature of Loki, the most powerful volcano on Io (Rathbun et al., 2002). Many fundamental questions about Io's volcanoes have not been addressed because the ground-based data have not been available in an accessible public archive. We propose here to make the data available to the entire scientific community, not just those who have the specialized tools to deal with arcane photometric calibration and timing/ephemeris/location information.

The first set of data consists of observations of Io in eclipse and while being occulted by Jupiter. We will create occultation lightcurves in PDS table format to share with the community. These lightcurves show a step whenever a volcano is occulted by Jupiter's limb. The height of the step indicates the strength of the volcano while the timing indicates, in one-dimension, the location of the volcano on the surface. We will share a program that determines this location based on the time of the observation of the step.

The second set of data is mutual satellite occultations of Io from 1985 through 2015. Mutual events provide the highest spatial resolution available from ground-based data, and in addition this long time span provides a unique record of longer-term variations. We will share lightcurves from the mutual occultations as well as tomographic reconstructions (2-dimensional images) of the brightness of any active volcanoes observed.

Finally, we will test multiple ephemerides to determine which is the most accurate. Our resulting data and ancillary programs will be shared in the PDS and on GitHub, in easy to use formats, such as tables and 2D images, which are calibrated in physical units and include spatial information.

James Roberts/Johns Hopkins University Applied Physics Laboratory
Updated Geologic Database for 433 Eros

The topography of 433 Eros has been determined using the NEAR Laser Rangefinder (NLR), and from imaging data using classical stereo, and stereophotoclinometry (SPC). This last technique combines stereo effects and photoclinometry to simultaneously solve for slopes and albedo variations. Shape models based on all these techniques are available in the PDS. The SPC shape model has the highest resolution, but is based on only a

fraction of the available NEAR images. Because of small errors in spacecraft trajectory and pointing, the locations of images not used in the creation of the shape model may be slightly shifted, making it difficult to correctly map structures contained therein.

As an example, of the 334 ponds (smooth deposits that sharply embay their bounding depressions) identified on Eros, only 55 are located in images registered to the high-resolution SPC shape model. The topography of ponds on Eros can be useful for evaluating proposed formation mechanisms, but only if they can be precisely located on the surface with respect to the background gravity and slopes. There are other examples of geologic features mapped on one shape model, and which would be valuable to project to the other, including the distribution of craters and ejecta blocks, and a set of lineaments that ties together surface history and internal structure.

We are currently in the process of registering the remaining NEAR images to the SPC shape model. Once registered, the shift in image locations between the shape models can be used to reference geologic features mapped on one shape model to their appropriate locations on the other. The primary objectives of our work will be:

Objective 1: To accurately locate all ponded deposits and lineaments with respect to the SPC shape model of Eros.
Objective 2: To make updated databases of pond sizes and locations and lineaments available to the scientific community.

In pursuit of the scientific objectives described above, we propose three specific tasks:

Task 1: We will update the locations of known pond deposits and mapped lineaments onto the highest-resolution shape model of Eros, generated using SPC. A database of the pond sizes and locations will be archived in the PDS and incorporated into the Small Body Mapping Tool. (Objective 1).
Task 2: We will produce additional maps at higher resolution than those used in the global shape model in the vicinity of ponds and in regions of geologic interest (Objective 2).
Task 3: We will incorporate the updated image pointing and shape model, the geologic databases, and high-resolution maps into the publicly available Small Body Mapping Tool, maintained by APL, and will archived these products into the PDS (Objective 2).

Relevance to the Planetary Data Archiving, Restoration, and Tools Program

The shape model of Eros and pond database we propose to created and archive in the PDS will increase the amount and quality of archived data digital information and data products available for planetary science research and exploration. The inclusion of these datasets in the publicly available SBMT will enhance future scientific investigations of the topography of Eros, and the nature of the ponded deposits. The proposed work thus directly responds to the objectives of the PDART program.

Huiqun Wang/Smithsonian Astrophysical Observatory
Mars Daily Global Maps for Mars Reconnaissance Orbiter Mars Color Imager

The objectives of this proposal are to make high quality Mars Daily Global Maps (MDGMs) using publically released Mars Reconnaissance Orbiter (MRO) Mars Color Imager (MARCI) raw images, and to archive the product in the Planetary Data System (PDS) Imaging Node.

The MRO MARCI MDGMs extend the nearly continuous daily global mapping of Mars established since the Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) MDGMs. Together, they form a unique data set which will be the base for numerous scientific research and applications.

MDGMs are highly useful for studying time variable phenomena on Mars, such as changes in the surface albedo, polar caps, clouds and dust storms. Better knowledge of these phenomena will greatly improve the understanding of Mars, and provide valuable information for future Mars missions.

The raw MRO MARCI images are difficult to use directly. We process these images into MDGMs that are much more user friendly and disseminate the product through the PDS to the public.

This proposal is relevant to PDART because it addresses PDART's objective of "increase the amount and quality of digital information and data products available for planetary science research and exploration".

Renee Weber/NASA Marshall Space Flight Center
Apollo Passive Seismic Experiment Expanded Event Catalog

The Apollo Passive Seismic Experiment (PSE) Event Catalog in its current form contains information on the timing, amplitude, quality, and type of seismic event recorded by the seismometers that were installed on the Moon in the Apollo era. Since the latest catalog update in 2008, many studies have provided new moonquake signals, improved signal classifications, revised source location estimates, and made focal mechanism estimates. In addition, it has been determined that the Apollo 17 Lunar Surface Gravimeter (LSG) acted effectively as a seismometer during the same operation period of the PSE, and indeed recorded moonquake signals. Lastly, the Apollo 17 Lunar Seismic Profiling Experiment (LSPE) was operated in "listening" mode during the period of interest, and this data has not yet been evaluated on the basis of individual events.

We propose to create an expanded lunar seismic event catalog that introduces new categories for event parameters and integrates the latest information on newly discovered events. Part of this catalog will include Geographic Information Systems (GIS)-

compatible digital format seismic event locations for visualization purposes. The goal is to consolidate the body of knowledge on lunar seismicity into a single referenced document, such that a new user could have at their fingertips access to the most current state of knowledge on any single type of lunar seismic event.

Our methodology will focus on updating the existing catalog to contain newly discovered events, missing catalog information, and new categories for event location, focal mechanism, and phase picks:

1. It has already been confirmed that the LSG recorded known moonquake signals. We will update the catalog to reflect a new station identification in those cases, and process the LSPE and newly-recovered LSG data to identify additional cataloged events.

2. We will apply a hidden Markov model-based event detection and classification algorithm to all available data. This algorithm serves two purposes: first, it can detect new events (not previously cataloged). Second, it can help classify known events not currently assigned to a specific event type. An initial re-examination of station 16 PSE data revealed significant numbers of non-cataloged events. We will apply this technique to the remaining data in order to obtain a new list of events.

3. We will provide compressed-scale amplitudes for those events not so assigned in the existing catalog.

4. Numerous studies have investigated event locations, focal mechanisms, and phase picks. We will incorporate all such information available in the literature, as well as the improved locations we expect to gain from the event recovery analysis.

NASA's Planetary Data NASA's Planetary Data Archiving, Restoration, and Tools (PDART) program solicits proposals to generate new reference information and create/consolidate reference databases. As we move towards an era of renewed attempts at planetary seismology, there is significant new demand for the lunar seismic data. The InSight mission, which will emplace a next-generation seismometer on Mars, is set to launch in March 2016, and a Lunar Geophysical Network is among the candidate missions for NASA's New Frontiers 5 announcement of opportunity. Many researchers have and will continue to attempt to learn from Apollo, which remains the only source of significant extra-terrestrial networked geophysical observations. Providing an expanded lunar seismic event catalog, along with GIS visualization capabilities, will benefit all those who seek to work with the Apollo data in the future. To aid in these efforts, we plan to archive our catalog with NASA's Planetary Data System, as well as with the Apollo Lunar Surface Experiment Package (ALSEP) web portal maintained by the Lunar and Planetary Institute (LPI).

Paul Withers/Boston University
Archiving Ionospheric Electron Density Profiles from the Viking Orbiters

Description of science goals and objectives
The objective of this proposal is to recover ionospheric profiles acquired by the Viking Orbiter Radio Occultation Investigation from a data file made available to us, clean them, document them, and package them for archiving at the PDS.

Methodology
A Viking-era ionospheric scientist recently delivered to us ASCII versions of 73 Viking Orbiter radio occultation electron density profiles. These were delivered to her many years ago by the late Arv Kliore, instrument team leader. Upon an initial inspection, the profiles agree with small, cramped versions shown in figures of published articles. However, important ancillary information such as latitude and longitude is lacking. We propose to perform sanity checks on all these profiles; to use SPICE to determine missing ancillary information; to package the whole dataset for archiving at the PDS; and to resolve liens identified by the PDS.

Relevance of proposed research to this call for proposals
The vertical profiles of ionospheric electron density that were acquired by radio occultations conducted by Viking Orbiters 1 and 2 are some of the most useful datasets ever acquired for investigations of the planet's ionosphere. These data products have very small measurement errors and excellent vertical resolution. Despite the availability of 5600 MGS radio occultation electron density profiles at the PDS, these Viking profiles are still valuable. They extend to much higher altitudes, cover locations and solar zenith angles not sampled by MGS, and come from a different solar cycle. They are not currently publicly available.

This proposed effort is aligned with section 1.3 "Data Set Restoration and Archiving" of the PDART call for proposals.

Naoyuki Yamashita/Planetary Science Institute
High-Resolution Gamma Ray Spectra for Lunar Geochemistry from Kaguya

Science goals and objectives
The objective of the proposed work is to give the planetary science community access to the Kaguya Gamma-Ray Spectrometer (GRS)
data, the best global lunar chemistry data that have ever been obtained, in an easily accessible and usable way for the study of lunar
geochemistry.

The ability to identify elements and determine their concentration depends in large measure on the energy resolution of the gamma ray spectrometer. The resolution achieved by the Kaguya GRS was as much as 20 times better than that of previous

missions (Table S1). Consequently, Kaguya enabled unique identification and quantification of many more elements on the Moon that were impossible with data from previous missions. However, the Kaguya GRS data have been under-utilized, because of the lack of a high-order, calibrated data product that is available to public.

We propose to produce and archive complete, fully-calibrated and corrected time-series spectra of the Kaguya GRS as peer-reviewed, Level-1B (L1B) products at Planetary Data System (PDS), which is freely accessible by the lunar science community. We have the permission of the instrument PI and JAXA to access the raw data and to release the calibrated spectra to the PDS. The PDS Geosciences Node has expressed its interest in accepting our data.

The resulting L1B product will accomplish the science goal of this proposed work, which is to help users identify and more accurately quantify elements such as K, Th, U, H, O, Na, Mg, Al, Si, Ca, Ti, and Fe to study the origin and evolution of the Moon.

Table S1 Geochemical observations of the Moon with gamma rays

Mission	Launch	Detector	Resolution* (keV	Altitude (km)
Apollo 15/16	1971/1972	NaI(Tl)	50	100
Lunar Prospector	1998	BGO	80	100**
Kaguya	2007	Ge	4	30 × 50

*Energy resolution is expressed as the full-width-at-half-maximum of the 662 keV gamma ray from 137Cs.
**Elemental maps were derived using high-altitude data by Prettyman et al., 2006. Maps of Fe and Th have also been produced using low-altitude (30 km) data (e.g. Lawrence et al, 1999, 2002).

Methodology

Data reduction processes, similar to those for Lunar Prospector and Dawn missions, will be applied to the raw time-series spectra of Kaguya GRS to create a L1B product. Data reduction steps include:

(1) Filtering of events unsuitable for scientific analyses;
(2) Correction of analog-to-digital converter differential non-linearity;
(3) Gain correction and energy calibration;
(4) Correction for variations in satellite altitude and galactic cosmic ray intensity;
(5) Derivation of ephemeris data for mapping of spectra and counting products.

Ancillary data needed to analyze and interpret the data, such as detector response functions and documentation, will also be developed and included in the archive. For validation purposes, the derived dataset will be compared with results from Lunar Prospector.

Relevance

The reduced high-resolution gamma ray spectra will significantly improve the quality of archived data in the PDS for the study of lunar geochemistry. Kaguya raw data are proprietary. Archiving the reduced Kaguya GRS data at PDS will provide the planetary science community the full, validated and calibrated Kaguya data set for use in scientific studies. Consequently, this proposal is directly relevant to the call by the PDART, whose objective is "to increase the amount and quality of archived data and data products available for planetary science research and exploration."