Planetary Data Archiving, Restoration and Tools 2017
Abstracts of selected proposals
(NNH17ZDA001N – PDART17)

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. 81 proposals were received in response to this opportunity. October 30, 2017, 16 proposals were selected for funding.
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Barth, Erika/Southwest Research Institute
A Vapor Pressure Database for Modeling Planetary Atmospheres

Atmospheric modeling involving the condensation process, such as in photochemical or microphysical models, requires knowledge of the vapor pressure of the condensing species as a function of temperature. Additionally latent heat values, which can be related to the vapor pressure through the Clausius-Clapeyron equation, are important when modeling energy transport processes. Online reference sites such as the NIST Chemistry WebBook contain formulations of the vapor pressure for many species found in the planetary atmospheres of our solar system. However the NIST equations most often report data for the liquid phase, whereas at the colder temperatures in outer solar system, these species would condense as ices. There have been some works in the literature that compile lists of vapor pressure equations and data points for sublimation, but an online database allowing the user to perform calculations or create plots over a desired temperature range is lacking.

Objectives and Methods: In order to provide the planetary science community with a single repository, a set of modules in both Fortran 90 and python will be created. Each module will contain a set of functions for each vapor pressure reference, including information from the primary source detailing the temperature range over which the measurements were made, allowing the user to calculate vapor pressure values (and latent heat) as a function of input temperature. The python code will additionally allow for graphical comparison of multiple reference equations over a user specified range of temperatures to check for validity. Both solar system and exoplanet atmospheres will be considered for the list of condensing species.

Significance to PDART: Two elements of the PDART program are to create or consolidate reference databases and develop or validate software tools. We will be consolidating information from various sources into a single repository for the planetary science community to access in order to calculate vapor pressure and latent heat values as a function of temperature. We will be developing new software tools to perform these calculations. These program modules will then be archived with the NASA Github site for use by the planetary science community. This project does not include a hypothesis-based science element and is therefore most appropriate to the PDART program.

Beyer, Ross/SETI Institute
New High Resolution Topographic Maps of Pluto and Charon

OBJECTIVES: To produce higher-resolution digital terrain models of Pluto and Charon than will be deposited by the New Horizons team into the PDS, by using additional high resolution images, and photoclinometry in near-terminator areas. We will also take advantage of limb profiles that transect areas of both bodies where high-resolution coverage is not available, to extend topographic information to the non-encounter hemispheres of Pluto and Charon.

METHODOLOGY: New Horizons revealed complex and diverse geologic processes on the icy dwarf planet Pluto and its moon Charon. The topographic expressions of these worlds reveal their geologic histories and are equally complex, with relief of multiple kilometers over short distances. The charter of the New Horizons mission to Pluto was to complete a global base map and topographic map of Pluto and Charon using stereogrammetry, which has now been done and will be submitted to the PDS this fall. In this proposed work we will augment and improve on these maps using additional high-resolution images from the New Horizons imaging systems to both improve the resolution of the the topography locally by 3-to-5 times the current value and to extend our topographic mapping to areas not covered by stereogrammetry. First, we will produce high-resolution stereo products for the 3 LORRI "noodles" that track across Sputnik Planitia, and that were NOT processed as part of the official New Horizons archival data sets. Even so, as stereogrammetric toolkits rely on scene-recognition, which blur the topography by 3-5 times the low resolution component of the stereo observations, this degrades the map resolution significantly. We will use shape-from-shading (photoclinometry) to map areas with low Sun illumination near the terminator during the encounter to locally improve DEM resolution to almost the original pixel-scale of the original images ~315 m/pixel using the MVIC scan and 125-to-80 m/pixel in the LORRI image "noodles". These will provide the only usable topographic information in "glacial" valleys, small craters, and for the cellular pattern and small pits common across Sputnik Planitia. Both the stereogrammetry and photoclinometry techniques produce results only over the high-resolution encounter hemisphere, which is about 40% of the surfaces of each body. In other poorly resolved areas of the surface, significant relief was apparent (or its absence was apparent) in areas viewed on the limb of the disk of each body. In some cases, backlighting due to bright atmospheric haze revealed relief along limb views of the disc of Pluto that would otherwise have been unseen. We will use limb profiles as narrow strips of topographic data to examine the ruggedness and relief of areas and geologic units that are not otherwise resolved well or were even in darkness in 2015. These techniques will allow researchers to characterize the topography of as much of Pluto and Charon as is possible from the New Horizons data set.

RELEVANCE: The result of funding this PDART proposal will be several terrain products and data sets of Pluto and Charon derived from spacecraft data that would not otherwise be produced and archived by the New Horizons project. Ensuring that these data get created by our proposal team (who are intimately knowledgeable about the instruments and the mission) and released to the public will ensure that any scientist who

wants to perform topographic studies of these worlds will have access to the best possible terrain data available.

These proposed outcomes are directly relevant to the PDART call which seeks "to increase the amount and quality of digital information and data products available for planetary science research and exploration ..."
The resulting data products will be archived according to the PDART requirements.

Cooper, John/NASA Goddard Space Flight Center
Plasma and Energetic Particle Archive for Jovian Magnetospheric Interactions with the Galilean Moons

The interactions of the Jupiter magnetosphere with the four Galilean moons, as observed in greatest detail by the Galileo Orbiter spacecraft during 1995 - 2002, are complex and progress from the first disturbances in the upstream environment through the close-in interactions with the moon neutral atmosphere and ionosphere, continue deeply below the icy surface to the moons' putative sub-surface oceans via magnetic induction effects, and finally sweep past the moons into the downstream field and plasma tail environments. In the future the moons and their magnetospheric interactions will be investigated further by the JUpiter ICy moons Explorer (JUICE) and Europa Clipper missions with respective focus on Ganymede and Europa. In this investigation we focus on Galileo Orbiter and Voyager data products that potentially enable modelers to address the following science questions for moon-magnetosphere interactions: (1) what are the upstream magnetospheric environments incident on the four moons, (2) how do the plasma and energetic particle environments evolve on direct interaction with the moon surfaces, neutral atmosphere, ionosphere, and conductive sub-surface layers, and (3) how do the modeling perspectives change in the magnetospheric and moon environments as viewed across the full ensemble of measurements from plasma to higher energies, as if the various measurement were being made by one composite instrument?
The Planetary Data System's Planetary Plasma Interactions node provides a wealth of archived magnetic field, plasma, and energetic particle measurements in the Jupiter system from Galileo Orbiter, the twin-spacecraft Voyager and Pioneer missions, Ulysses, and most recently New Horizons, but our knowledge of the near-moon environments comes only from Galileo Orbiter. The lack of thermal core electron measurements below 100 eV from Galileo's Plasma Spectrometer requires that we also examine the earlier data from the Voyager Plasma Spectrometers. Even for Galileo Orbiter the full range of instrument measurements for plasma and energetic particles are not yet manifested in the data products archived to date. The record-mode highest resolution data from the Galileo PLS have not yet been archived, and the energetic particle data products from the Energetic Particle Detector (EPD) and the Heavy Ion Counter (HIC) are not yet mapped spatially and directionally into moon-centered coordinates. For the upstream magnetosphere there only plasma moments but not full resolution flux spectra from Voyager 1 and 2 PLS. Major advances in understanding the moon-magnetosphere interactions may come from ongoing from ongoing development of simulation models

but these models need boundary conditions and constraints on key parameter values that are not readily available from the archived data.

The proposed investigation includes the following objectives for improvement of the Galileo Orbiter and supporting Voyager archives: (a) Upgrade the current PDS-PPI holdings from Galileo PLS, EPD, and HIC, along with plasma electron and ion data from Voyager PLS, to improve data on initial conditions for modeling the upstream magnetosphere near the orbits of the four Galilean moons; (b) Upgrade the current PDS-PPI holdings from Galileo PLS, EPD, and HIC to improve data on high-resolution record-mode measurements during each moon flyby; (c) generate and archive new multi-sensor flux distributions from Galileo PLS, EPD, and HIC for all magnetospheric and moon-flyby time intervals.

NASA GSFC leads the overall project and specific work on new PDS4 data bundles from Galileo PLS. The existing Voyager PLS team at the Massachusetts Institute of Technology leads on the Voyager PLS work. Fundamental Technologies LLC leads on generation of new Galileo EPD data bundles and provides expertise as a PDS-PPI subnode on PDS4 archiving formats and procedures. The California Institute of Technology leads on HIC data bundle generation with additional support from GSFC.

Davies, Ashley/Jet Propulsion Laboratory
Incorporating Galileo NIMS Io volcanic thermal emission products into the PDS

A vast trove of multi-wavelength infrared data of the volcanic Jovian moon Io was collected by the Galileo Near Infrared Mapping Spectrometer (NIMS) between 1996 and 2001 (>1000 hot spot detections in total; e.g., Davies et al., 2012, GRL, 39, L01201). The goal of this work is to derive a high-level product set, from NIMS data, for the NASA Planetary Data System (PDS). These products will consist of the integrated volcanic thermal emission from each individual hot spot identified in every NIMS observation of Io. This product does not exist within the PDS. This product is important as the measurement of thermal emission forms the basis of modelling Io's volcanic eruptions. The temporal variability of individual volcanic centers is desirable for understanding the eruption processes taking place and, ultimately, quantifying the transfer of heat from the interior of Io to the surface. Current estimates of thermal emission derive from all available NIMS data and, more importantly, a full examination of the temporal variability of thermal emission, are available for only a few of Io's hundreds of hot spots. These "full" analyses are available only in journal publications. Aggregating these and the other as yet unprocessed (and more numerous) NIMS hot spot thermal emission data into PDS4 products will make them fully accessible, and provide the basis for further research, enabling the comparison to and integration with other Io data. NIMS obtained the best dataset of Io's volcanic thermal emission currently in existence, in terms of the temporal coverage and spectral and spatial resolution ranges of detected hot spots. This invites further comparison with other Io data, such as those collected by the InfraRed Telescope Facility (IRTF) and large, ground-based telescopes equipped with Adaptive Optics (such as Keck, Gemini, and the Large Binocular

Telescope Interferometer).

Our objective is to create a new high-level NIMS-derived product of at-surface leaving radiances from Io's volcanic hot spots. This work will use previously established techniques. These thermal emission products will be useful to planetary scientists by making the NIMS volcanic thermal emission data more easily accessible.

The methodology is as follows. With the assistance of the NMSU PDS, we will design label and data structures for output products, liaising with the NMSU PDS node to ensure that PDS4 compatibility and data format standards are met. Our work plan is as follows: (1) Design data processing code (using IDL). (2) Quantify the thermal emission from each NIMS observation using the list of detections in NITED, the NIMS Io Thermal Emission Database (Davies et al., 2012). (3) Check accuracy of results. (4) Create IDL structure to hold this database and read in data. (5) Write data and label information to PDS product form. (6) Review, verify, and validate products. (7) Generate and deliver final products to PDS. Final products include ancillary information products in the form of plots of model fits to the NIMS data and the expanded NITED (which we call NITED+). NITED+ will incorporate the new thermal emission estimates. Software used for fitting the NIMS Io hot spot data will be made available via NASA's PDS Github site.

This work is highly relevant to the PDART program as it generates a new, higher-level product from spacecraft data in the DPS. The products to be generated will increase the amount and quality of digital information available for planetary research, specifically for Io studies, allowing detailed examination of the evolution of Io's volcanic activity. This is highly relevant to future NASA and ESA missions to the Jovian system (Europa Clipper and JUICE), JWST observations, possible future Io-directed missions, and NASA-supported ground-based telescope observations (e.g., Keck).

Elwood Madden, Megan/University Of Oklahoma, Norman
Raman Spectral Database of Aqueous Solutions for Planetary Science

Seasonally active brines observed on Mars surface as well as the presence of salts in plume jets on Enceladus suggest that briny waters may be common throughout the solar system. Modern brines likely contain important clues toward understanding the geologic history, current subsurface conditions, and potential habitability of these and other planetary bodies. However, traditional techniques used to detect and measure aqueous components in planetary and terrestrial waters rely on direct sampling and analysis, which can lead to clogging and corrosion when applied to brines. Raman spectroscopy, which measures the vibrational energy of covalent bonds by exciting the sample with laser light, then collecting the photons produced by the excitation, can remotely detect and measure aqueous components in very small samples, with little to no sample preparation. Therefore, Raman spectroscopy could be used to remotely analyze pore water, fluid inclusions, and/or grain coatings, in addition to bulk water samples, while enhancing planetary protection. For example, Raman has been previously utilized to determine pH conditions in microliter samples of ancient sulfate-rich waters trapped as fluid inclusions (Benison et al. , 1998) and determine nutrient concentrations (N and P) in

seawater using Surface Enhanced Resonance Raman Spectroscopy (SERS) at nanomolar concentrations (Sharma and Taylor, 1991). Preliminary research in our laboratory demonstrates that Raman spectroscopy can be used to evaluate aqueous carbonate, nitrate, phosphate, sulfate, and perchlorate concentrations in near-saturated NaCl, CaCl2, MgSO4, Na2SO4, and NaClO4 brines. However, reliable, well documented reference Raman spectra are required in order to support future missions which may encounter aqueous planetary samples.

We aim to create a new reference database of aqueous Raman spectra by generating new reference spectra from endmember near-saturated (CaCl2, Na2SO4, MgSO4, NaCl, NaClO4) to which known concentrations of sodium salts with C, N, P, S, and Cl-bearing anions are added. Solutions will be analyzed using a 532 laser and the signal for each known standard will be measured to determine detection limits and develop calibration curves. We will build upon these initial solute measurements in year 2 to determine the effects of varying pH and temperature on aqueous Raman spectral signatures by collecting Raman spectra throughout pH titration and temperature ramp experiments. In year 3 we will measure Raman spectra from mixtures of brine + solid matrix composed on basaltic sediments, clay minerals, or water ice to determine aqueous Raman detection limits in heterogeneous systems and further develop a suite of planetary-analog reference spectra.

These spectra and calibration curves will be utilized to generate new reference spectra and develop a database of Raman spectra for planetary exploration of aqueous solutions which will be archived in the publically available, NASA supported, Planetary Data System. Future researchers can download and use these reference spectra and calibration curves to support Raman-based techniques aimed at analyzing planetary fluids on Mars as well as icy planetary bodies, including Enceladus and Europa. Data from this study can be used to interpret Raman spectra to Assess habitability on different scales (Astrobiology Strategy 5.4, I, Hays et al., 2013), Determine any past or present habitable environments, prebiotic chemistry, and signs of life elsewhere in our Solar System , and Determine the history of any environments having liquid water, chemical ingredients, and energy sources that might have sustained living systems& (Astrobiology Roadmap Goal 2, DesMarais et al, 2008). Therefore, this reference data and spectral archive will expand the knowledge gained and return on investment from Raman spectrometers that may be deployed for planetary exploration within the next decade, fulfilling the primary mission of the PDART program.

Espiritu, Raymond/Johns Hopkins University
Converting PDS4 Data to Common Formats

Proposal Title - Converting PDS4-formatted Data into Common Data formats.

Summary

We will create a software tool for converting PDS4 data products into other commonly used file formats, including CDF and FITS. The tool will leverage existing tools designed to generate PDS4 data from various sources. Our team has significant experience working with many of the different types of science products currently in the PDS, from images to tabular data. Also, our team was one of the first teams to formally deliver mission data in PDS4 format.

1. Scientific/Technical/Management

1.1. Introduction

With the introduction of PDS4 XML based labels and the use of the XML object model it is now possible to easily create an object model of the data format, parse the data, and repackage it into another, more commonly used file format. PDS4 XML objects contain elements defining all parameters needed to parse the data file, while the XML organization allows open-source libraries to access and manipulate the objects and object elements contained within the XML label.

Our team has extensive mission experience with file formats commonly used by the planetary science community. The Johns Hopkins Applied Physics Laboratory (JHU/APL) was one of the first organizations to submit a PDS4 archive with data from the Balloon Observation Platform for Planetary Science (BOPPS)[1]. UCLA hosts the PPI node of the PDS, and has relevant experience with PDS4, as well as PDS3 file formats. We also routinely deal with CDF data products, which are more typical of Heliophysics missions. We have recently created and are actively using software tools that convert multiple input types into PDS4 data. This proposal would further develop those tools to reverse the direction of data creation and convert a PDS4 formatted file back to a common file format such as FITS or CDF.

The pool of archived data in PDS4 format is still relatively small but is certain to expand as current and future NASA missions deliver archives in PDS4. NASA is considering a significant conversion effort to move many older PDS3 archives to PDS4 format. Thus it is a good time to focus on making PDS4 data more usable. Many older PDS3 archives have data formats that are not commonly used or may have been mission specific. The proposed software would be useful for both scenarios.

1.2. Methodology

We intend to:

1. Develop software tools that will map PDS4 XML labels to an internal data model representing the data content described by the label.

2. Develop software to read PDS4 data into our internal data model
3. Create several output options for writing out the internal data model to one of several common output formats.
4. Provide our software as
   a. an application that can convert PDS4 files to other formats
   b. a Java library for use in creating other conversion applications
5. Demonstrate the proposed tool by converting several PDS4 datasets to FITS and CDF format.
6. Make the source code, the executable, and the library available online at the Github location required by the AO:
https://github.com/NASA-Planetary-Science

1.3. Relevance
This proposal will enhance the usability of, and access to, PDS4 file formats. Successful conclusion of this project provides NASA with a valuable resource that enables users to access PDS4 data in file formats which they are already accustomed to using or for which applications already exist.

References
[1] Cheng A.F. et al (2014) Icarus, doi: 10.1016/j.icarus.2016.08.007

Gaddis, Lisa/USGS Flagstaff
Kaguya Orbital and Geometric Restoration

Objectives: The objective of this proposed work is to improve the geometry of the high-quality, high-spatial-resolution Kaguya extended mission (XM) data for the Moon by refining their orbit and trajectory solutions. We will then demonstrate the value of these improved orbit solutions to other Kaguya data by creating and evaluating a pilot mosaic (~10ýx10ý in size) from the Kaguya Terrain Camera (TC) for the Apollo15/Hadley Rille region.

The Japanese Space Agencyýs (JAXA) SELenological and ENgineering Explorer (SELENE) or ýKaguyaý spacecraft mission to the Moon returned high-quality, high-resolution monochrome and color images as well as laser altimeter data. Launched in September 2007, the Kaguya primary mission (PM) was completed at the end of October 2008 and the extended mission (XM) phase started at the beginning of November 2008. During XM Kaguya was in a lower orbit at 50 km average altitude compared to 100 km during PM, and until the end of the mission in June 2009, the Kaguya spacecraft was put into several even lower orbits to perform additional science and engineering observations. Kaguya instrument products using XM data thus have higher spatial resolution than the PM data. However, the geodetic position information of these products is much worse than that of those acquired during the PM: after the PM, radio tracking of Kaguya (necessary for determining the spacecraft's position precisely) was reduced, and in addition the loss of momentum wheels resulted in frequent thrusting to maintain attitude, which further complicates the orbit determination process. As a result, the degraded orbit

quality during XM (at a level of several km compared to 10-30 m during PM) severely limits the scientific value of these high-quality data.

To refine the XM orbit and trajectory solutions, we will reconstruct the Kaguya XM trajectory by leveraging two recent developments: 1) the availability of high-quality, high-resolution Gravity and Interior Laboratory (GRAIL) gravity fields, which have drastically improved our knowledge of the lunar gravity field, and 2) the use of a new and unique altimetric measurement type in the orbit determination process, where we can use Kaguya Laser Altimeter (LALT) data as a direct measurement to adjust the orbit so that the LALT topography profiles fit the high-precision Lunar Reconnaissance Orbiter's (LRO) Lunar Orbiter Laser Altimeter (LOLA) topography map. The resulting Kaguya XM orbit will be geodetically accurate and directly tied to the LOLA/LRO frame. Project deliverables will include the improved Kaguya trajectories in SPICE format, geodetically-accurate LALT altimetric and LMAG magnetic data updated geolocation records, the regional controlled TC mosaic and ISIS3 ingestion and camera model software for TC, and the data products will be archived with the NASA PDS and the Japan Aerospace Exploration Agency (JAXA) archives. Expected results of this proposed work will have substantial impact on the U.S. lunar science community because we will both greatly improve the quality of the Kaguya XM data and significantly enhance their accessibility and usability.

Garcia, Patricia/USGS Flagstaff
Expansion of Planetary Data System (PDS) Archive of Lunar Mapping and Modeling Program (LMMP) Products

Goals and objectives: The objective of this data restoration and archive proposal is to archive data products that have already been generated by NASA s Lunar Mapping and Modeling Program (LMMP). This proposal is for the expansion of a Planetary Data System (PDS) archive which is currently in progress under 14-PDART14_2-0084.

In 2014, we submitted a successful 2-year PDART proposal to archive a select group of products that were generated under the LMMP. The LMMP data products currently being archived under the original PDART-2014 proposal include mosaic, DEM (digital elevation model), hillshade, colorshade, slope and confidence data associated with 50 LMMP-designated lunar Region of Interest (ROI) sites. Each ROI had scientific or operational characteristics that warranted its selection as a potential site for future robotic or human landings. Work under the original PDART-2014 proposal began on October 1, 2015 and will be completed by September 30, 2017. The archive will be made public at that time.

However, the LMMP also generated many additional products which were beyond the scope of the original PDART-2014 proposal. This new PDART-2017 proposal focuses on expanding the original archive to include these products. We propose to expand the archive that is currently in progress with LMMP albedo, crater and rock abundance and density, gravity, mineralogy, roughness, and temperature related products. We will also

archive additional resolutions and geographic extents for the regional and local image base maps (LRO-NAC and Apollo Metric and Panoramic sources) and DEMs currently being archived. As with the collection of data products currently being archived, these additional LMMP products are important resources in support of current and future scientific research and exploration activities on the Moon and other Solar System bodies. They were generated at a cost of several million dollars and should be preserved. The additional data products cover themes within and beyond the 50 ROI sites.

History: The LMMP was a Lunar Precursor Robotic Program (LPRP) project tasked in 2006 by the Exploration System Mission Directorate (ESMD) Advanced Capabilities Division to create useful cartographic products and visualization and analysis tools from lunar datasets in support of the Constellation Program (CxP) as well as other lunar exploration and research activities. Our existing PDART-2014 project accomplishes the initial effort of creating an archive of LMMP data products to support continuing scientific study.

Methods: PDS data archives preserve the data products and include the documentation and ancillary data necessary for future scientists to interpret and use the data long after the original instrument and project teams have been dissolved.

The proposed expanded archive will comply with PDS standards, ensuring long-term usability and preservation of the science data. Archiving steps will include incremental archive design, local staging of the data products, data conversion (as needed), production of ancillary products, and generation of documentation required for compliance with PDS (PDS4) archive standards. Some software development may be required in order to accommodate conversion of specific product formats and related metadata. Final steps will involve peer review, and final archive ingestion into the PDS (for science access), and deep archive with the NASA Space Science Data Coordinated Archive (NSSDCA).

Relevance: Archiving these additional LMMP products will directly address the PDART solicitation seeking to archive and restore data sets or products in line with specific program goals to increase the amount and quality of digital information and data products available for planetary science research and exploration . PDART archive and access requirements will be met because products will be made available to the scientific community and will be archived in the NASA Planetary Data System (PDS).

Garry, William/NASA Goddard Space Flight Center
Updating the Geologic Maps of the Apollo 15-16-17 Landing Sites

Pre-mission geologic maps of the Apollo landing sites preserve a unique moment in the history of human space exploration - the initial interpretations of the lunar surface prior to exploration by the astronauts. Creating updated geologic maps that merge surface observations and recent remote sensing data will provide a resource to give context for studies of the samples collected and analyzed, recent and future orbital data sets, and possible future surface exploration at these original landing sites.

The motivation for this project is based on the lack of GIS resources for the Apollo landing sites:
" There are no digital GIS files of the pre-mission geologic maps of the Apollo sites
" The USGS geologic maps for the Apollo landing sites have not been updated in over 40 years
" The ages of the geologic units have not been re-evaluated based on recent spacecraft images; higher resolution images enable new model age assessments based on recent re-calibration of the lunar crater chronology.

Our goal is to provide the community with a set of GIS-ready files for Apollo 15-16-17 missions that integrate pre-mission geologic maps, the traverse maps, and updated geologic maps. Proposed tasks relate to sections 1.2 (data product generation) and 1.6 (data digitization) in the PDART program.

Task 1. Digitize Pre-mission Geologic Maps of Apollo 15-16-17
We will digitally preserve the hard-copy pre-mission geologic maps for Apollo 15-16-17 missions in ArcGIS. These maps are a historical record of the early thoughts scientists had about the lunar surface. Apollo 15-16-17 each have a regional (1:250,000) and landing site map (1:50,000) that we will digitize. This task will be completed in Year 1 and files will be archived in the PDS Imaging Node Annex.

Task 2. Create New Geologic Maps of the Apollo 15-16-17 Landing Sites
We will produce new geologic maps: a regional (1:200,000) and a landing site (1:24,000) map for Apollo 15-16-17 landing sites. The new geologic maps will be at higher map scales to take advantage of new high resolution data sets. The maps will reflect surface observations, published results, and remote sensing data from recent missions. This task will begin in year 1 and be completed by year 3. Files will be archived in the USGS Publications Warehouse.

Task 3. Determine Crater-Derived Ages for New Geologic Map Units at each Apollo Landing Site
We will determine crater ages for the newly defined geologic units on each map from crater measurements. We will use publicly available crater databases in conjunction with new crater counts that will be conducted for selected units as part of this investigation; these new crater counts will serve to validate the crater measurements obtained from the published databases in addition to extending to smaller diameters when needed. We will

perform crater counts in ArcGIS using the CraterTools extension and absolute model ages will be determined using the CraterStats software. We will use high-resolution LROC NAC images (average 0.5 m/px), Kaguya Terrain Camera (10 m/px) and LROC WAC (100 m/px), as basemaps. This task will occur during years 1 through 3.

The new maps for Apollo 15, 16, and 17 will be published as USGS Special Investigation Maps (SIM).

The digitized pre-mission and updated geologic maps will be generated in ArcGIS 10.4. Basemaps will be derived from existing LROC WAC and NAC mosaics currently available in the PDS. Map projections will be Mercator, consistent with USGS planetary geologic mapping standards.

Our proposal to create new geologic maps will involve minor scientific interpretation to define map units and crater-derived ages, but this is not a hypothesis-driven mapping project.

Hayes, Alexander/Cornell University
Delay-doppler and super resolution processing of the Cassini altimetry dataset

Objectives: Topography is essential to understanding the formation and evolution of any landscape, as it permits a three-dimensional view of the interaction between geomorphic units and illuminates stratigraphic relationships. Unfortunately, topography on Titan is scarce. Fortunately, Cassini s altimetry dataset is an underutilized resource that has the potential to reveal diagnostic topographic relationships that can address the formation and evolution of specific morphologic features including dunes, mountains, craters, and empty lacustrine basins. The proposed project will employ proven along-track processing and bandwidth extrapolation techniques to improve the resolution of existing altimetry data and generate topographic profiles with km-scale along-track spacing (a factor of ~6 in improvement over existing products). These products can be used by the community to study the topographic signature of Titan's surface.

Methods: The proposed work will implement a Delay/Doppler processing algorithm in along-track directions and bandwidth extrapolations using Burg s Maximum Entropy Method (MEM) in the range direction. This processing will permit the discrimination of signals return from sub-footprint resolution on Titan s surface and results in a significantly improved altimetry data product. The increased spatial resolution of these products will permit the interrogation of topography at a scale that is up to six times better that what is currently available on the PDS, fine enough to resolve morphologic features such as dunes, individual inselbergs, and the wall slopes of empty lakes and large fluvial valleys. These super-resolution techniques were developed by Dr. Valerio Poggiali. The proposed investigation would fund Dr. Valerio Poggiali and the PI to apply these techniques to the entire altimetry dataset and make the results available to the community.

Relevance: The proposed investigation is relevant to goals of 2016 NASA Strategic Plan, the NASA Science Plan and the PDART Program. The proposed products will permit the characterization of topographic profiles of geologic features on Titan and is essential to understanding their formation/evolution. This is directly relevant to Outcome 2.3 in Strategic Goal 2 of the NASA 2016 Strategic Plan, to Ascertain the content, origin, and evolution of the solar system and potential for life elsewhere . The proposed is directly relevant to PDART as it will enhances the scientific return of the Cassini mission by providing a product that will allow researchers to develop a better understanding of how surface features formed and interact. The proposed altimetry products represent a significant advancement over existing topographic products for Titan. The processed altimetry products will be produce at a spatial scale that is approximately ten times smaller than previously studied, permitting direct interrogation of surface features that were previously unresolved. Derived altimetry products will be disseminated through the imaging node of the PDS. The PI has experience generating and delivering PDS products, and will conform to all of the PDS requirements.

Lehnert, Kerstin/Columbia University
MoonDB Phase 2: Restoration of Lunar Geochronological and Lunar Meteorite Data

Project Goals
MoonDB is a data system that restores and synthesizes historical analytical data from the Apollo lunar sample collection that is maintained and curated at the Johnson Space Center (JSC) in Houston, TX. The goal of the system is to ensure that the results of more than 4 decades of analytical work on this unique and irreplaceable legacy of the Apollo program are preserved and accessible for mining and re-use in future scientific studies. The MoonDB project, which has been developed with funding from NASAýs PDART program, has so far rescued and restored data and metadata from approximately 700 studies, including unpublished analytical data that are now fully integrated into a relational database. The database can be accessed online via an interactive user interface that will be released as a Beta version in June 2017.

In response to feedback received from lunar scientists during MoonDB outreach efforts, we here propose to extend the restoration of lunar sample data in MoonDB to (a) geochronological data and their associated metadata; (b) geochemistry and geochronology of lunar meteorites; to properly archive and integrate the MoonDB data with the Planetary Data System; to engage a broader lunar research community, especially early career scientists, in the data restoration and quality control/peer-review of ingested data.

Methodology
We propose to build on the achievements of the first MoonDB grant and continue the collaboration between the EarthChem team, curators and scientists at the NASA Astromaterials Acquisition and Curation Office, extending it to include experts in

geochronological data acquisition, data reduction, and data management at Arizona State University (K Hodges, C. Mercer) and the University of Kansas (D. Walker).
In order to accomplish the deliverables listed above, we will use the following methodologies: modify as needed data curation tools and procedures in use at MoonDB to rescue and restore geochemical data of lunar meteorites, making MoonDB a much richer resource for the science community; modify the MoonDB database schema and search application to accommodate the new data types and make them accessible via the user interface and APIs; modify the Geochron system to restore and preserve raw data for K/Ar, Ar/Ar, U-Pb, Sm-Nd and Rb-Sr geochronology, adopting metadata best practices that the community defined for Geochron. Raw data in Geochron will be linked to data in MoonDB by use of the IGSN, a persistent unique identifier for samples; recalculate historical lunar geochronology data with consistent and updated values of decay constants and monitor standards, working with K. Hodges and C. Mercer at ASU, who have developed the relevant software ArAR, to provide a set of consistent ages for lunar samples in MoonDB; build a MoonDB User Community, specifically engaging Early Career Scientists; establish a MoonDB Data Working Group that will meet on a regular basis to define and promote best practices for data formats, metadata content, and terminology. Members of the group will be asked to help build a network of researchers and analysts who are willing to review datasets for MoonDB.

Relevance
MoonDB is an advanced data system that provides a new, highly improved level of access to over four decades of published and unpublished chemical data of lunar rocks. It not only rescues and restores historical lunar sample data, but it accommodates data generated now and in the future, directly helping NASA and scientists studying the lunar sample collection to comply with government directives for Public Access in a way that maximizes the re-usability and utility of their data. Synthesis of the data and sample metadata in MoonDB allows unprecedented mining and analysis of these data and enables more targeted sample requests and future correlated analyses.

Mommert, Michael/Lowell Observatory
A Python Package for Small-Body Planetary Astronomy

The complexity of problems in small body research has grown exponentially over the last decades. Dealing with these problems requires not only powerful computational facilities, but also software tools to analyze these data sets in the most efficient way. For decades, planetary astronomers were required to produce their own software tools despite a lack of proper training in coding. As a result, efforts to solve the same problem have been duplicated multiple times in a variety of programming languages, usually without proper testing or documentation. While students and young researchers tend to have enjoyed a more comprehensive coding training, they often have to replicate and migrate already existing routines in order to use them for their own work. Hence, the lack of a maintained and well-tested open-source code base for planetary astronomy reduces the productivity of, especially young, researchers.

We propose the implementation of an open-source Python software package for planetary astronomy, designed for the needs of asteroid and comet researchers. This package will provide among others: observation planning and design tools; photometric phase curve, rotational lightcurve, and asteroid/comet thermal models and analysis tools; dust and gas activity models; utilities for the spectral and spectrophotometric analysis of small bodies, and routines supporting orbit fitting and integration, image and data analysis. These features have been identified in a survey within the small body community and additional features will be added in close collaboration with the community. The published code will be well tested, documented, and easy to use.

This Python software package focused on small body research - SBPy - will be developed by and for planetary astronomers in collaboration with the community. Our team consists of members of the asteroid and comet communities, who are also seasoned software developers. We will implement this package in Python, the by far most popular programming language among planetary scientists and astronomers. SBPy will combine the functionality of existing methods and software tools in a well-tested and documented code suite that will be easy to use by the community. All methods used in SBPy have been used in peer-reviewed publications. We will publish our code as an Astropy affiliated package that builds upon existing Astropy functionality and meets the high requirements of the Astropy community. Functionality that is relevant to other Astropy affiliated packages will be added there, as appropriate. SBPy will include a unique reference tracking system, building a bibliography in the background during use.

Code developed as part of this project will be available to the community at any stage during its development through a GitHub repository, enabling testing and contributions by the community. The final product will be hosted on NASA Planetary Science Division's GitHub site. In order to disseminate the package and its use we will provide example cookbooks, workshops and hackathons, for instance at meetings of the Division for Planetary Sciences, which will also enable us to stay in close contact with the community.

This project is relevant to NASA ROSES-2017 PDART, as it proposes to produce a software toolkit that will facilitate the use of existing and future data sets, as well as enable and enhance current and future scientific investigations in the field of planetary astronomy. Our goal is to create a core library that will serve as the gold standard and be of use to most comet and asteroid data sets and projects, whether they be astronomical in nature (telescopic observations), derived from mission data (flyby or rendezvous data sets), or are based on purely simulated data (e.g., from a Solar System Workings project). SBPy will boost the productivity of current and future planetary astronomers and small body researchers.

Pinilla-Alonso, Noemi/University Of Central Florida
PRImitive Asteroids Spectroscopic Survey (PRIMASS): the past as a puzzle

This is a 2-year proposal that aims to create and archive PRIMASS-L, a spectral library that would contain the results of the PRIMitive Asteroids Spectroscopic Survey (PRIMASS). These spectra are not available online or stored in any public database. With this addition, the PDS would increase the total amount of near-infrared spectra of asteroids in a 44% and the visible spectra in a 16%. PRIMASS-L would also be the first spectral library at the PDS dedicated to families of primitive asteroids. Along 2016 and 2017, we have been in contact with Dr. Neese of the PDS and she has provided useful guidance on the archiving process. The main tasks that this work would cover are:

(1) Homogenization and delivery of 500 to 750 proprietary spectra in the visible and near infrared of asteroids to the PDS to be presented as PRIMASS-L.

(3) Dissemination of the content of this library in international conferences.

(4) Publishing of a manuscript presenting PRIMASS-L goals and results.

In the last seven years, PRIMASS has focused on the families in the inner- and the outer belt, as well as in two dynamical groups, Hilda and Cybeles. Asteroids families are currently undergoing a revolution in understanding due to the combination of a rapid increase in asteroid survey data, and improved computational techniques. Gaining a better understanding of asteroid families provides a unique insight into the forces shaping both our Solar System and other planetary systems and the importance of impact physics in planetary scales. In particular, the families in the inner belt are the most probable sources of the two carbonaceous near-Earth asteroids (NEAs) that are the targets of the sample-return missions, OSIRIS-REx (Bennu) and Hayabusa 2 (Ryugu). Understanding the main belt sources of carbonaceous NEAs targeted by spacecraft improves our ability to predict their surface characteristics and provides a framework for interpreting the sample-return results, thus integrating smaller-scale details with the bigger picture of the Solar System origin and evolution.

Our plan is to make these data available during 2019, in proper timing to be used by the teams of the OSIRIS-REx (NASA) and Hayabusa 2 (JAXA) missions. PRIMASS-L will also serve as a quality-check database for the Gaia spectroscopic products that will be published on its final release by the end of the nominal mission in 2019.

As of July 2017, PRIMASS contains more than 470 spectra, either in the visible (0.4 to 0.9 microns) or near-infrared (0.8 2.3 microns). About 66% of this sample has already been published in peer-review publications. The list of works that already cite our publications demonstrates the growing interest of the community in PRIMASS-L. We anticipate that the creation and publication of this library would have a direct impact on (1) Studies of the surface of asteroids, (2) Studies of the asteroid families, (3) Laboratory works on carbonaceous chondrites, (4) Study of the distribution of the primitive matter in

the Solar System, and (5) Studies of mission targets.

The work proposed here is within the scope of the Planetary Data Archiving, Restoration, and Tools (PDART) Program element, for the following reasons 1) Improve and expand current high-order data products, 2) Archive a complete dataset, not shared through other dataset collections or public platforms of data sharing, 3) Create and consolidate a reference database useful for future planetary science research and exploration, 4) Support future planetary science exploration in particular by characterizing primitive asteroids in the inner belt that could be the origin of the targets of those missions, and 5) Provide a unique library in high demand for the study of asteroid families, and 6) Time-critical: we plan to do the job in two years to make it available to the community for the arrival of the first missions to their targets in 2018, and for the first releases of GAIA results on Solar System objects along 2019.

Stone, Thomas/USGS Flagstaff
Archiving the Lunar Image Dataset of the RObotic Lunar Observatory

A multispectral reflectance dataset of the near side of the Moon that covers a wide range of phase angles has many uses in planetary science. During 8+ years of operation, the RObotic Lunar Observatory (ROLO), located at the USGS Flagstaff Science Center in Arizona, acquired more than 110,000 images of the Moon in 32 wavelength bands from 350 nm to 2450 nm. The primary purpose of the ROLO lunar database was to develop a capability for on-orbit radiometric calibration for Earth-observing satellite instruments, and lunar calibration is now routinely used by NASA research instruments (e.g. NPP-VIIRS, MODIS) and operational satellite imagers worldwide. A subset of ROLO data also has been used to develop photometric corrections for the Moon Mineralogy Mapper (M3) and the Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC). To support wider use of the ROLO database for planetary science applications, we propose to process the radiance images into reflectance and archive these data in the Planetary Data System (PDS).

This work has three main tasks: converting the ROLO radiance images to reflectance, spatially processing the images to a map projection that is more useful for lunar science applications, and developing a PDS archive. The reflectance conversion involves measuring the disk-integrated irradiance from each ROLO image and computing the corresponding reference irradiance from the lunar irradiance model of the USGS Lunar Calibration system, in exactly the manner used for processing observations taken by spacecraft instruments that utilize lunar calibration. From these quantities, scaling factors will be generated and applied to convert the radiance images to reflectance at the absolute scale of the ROLO model. The second task will use existing image processing tools to convert the images from the at-telescope point perspective to a common uniform projection, such as Orthographic or Simple Cylindrical, thus enhancing their utility for lunar science work. The PDS archive of ROLO data will include the reflectance image database plus the supporting data used for the reflectance conversion and projection processing, and documentation as required for a PDS archive.

The proposed work addresses the PDART objective to "increase the amount and quality of digital information and data products available for planetary science research and exploration." Currently the ROLO database is not publicly accessible, and exists as at-telescope lunar radiance images which have not been mapped onto a standard spatial projection. This activity will produce an online PDS archive of the ROLO lunar reflectance and ancillary data in formats useful to the scientific community. Another PDART goal to "generate higher-order data products" is addressed by providing a lunar database with a demonstrated high-accuracy calibration, owing to the original purpose of ROLO and the USGS Lunar Calibration system to provide satellite instrument calibrations.

Wenkert, Daniel/Jet Propulsion Laboratory
Restoring and Archiving Voyager 1 Cruise Images of Uranus and Neptune

Neptune and Uranus are our solar system's ice giants, an important class of planets. Analyses of their atmospheres, albedos, and internal heat budgets require measurements of reflectance from a variety of phase angles. Voyager 2 flew by each planet, but it was unable to acquire full-disk integrated brightness outside of two narrow ranges of phase angle, corresponding to the approach to and departure from the planet. Voyager 1's narrow-angle imaging system (ISS-NA) measured full-disk reflectance, from many AU away, throughout the 1980s, as it cruised through the outer solar system. These data span much greater ranges of phase angle. Pollack et al. (1986) published phase curves for each planet, based in part on preliminary analyses by the PI of this proposal of some of these data. These analyses have been used in studies of the planets' atmospheres and their bolometric Bond albedos (Pearl and Conrath, 1991; Pearl et al., 1990) and, more recently, in the analysis of exoplanet phase curves (e.g. Sudarsky et. al., 2005, Figure 3; Cahoy et al., 2010, Figure 15).
Use of the published version of the data raises some concerns, because there are known issues with the old Voyager 1 reflectance data reduction. Specifically:
* We used a rough approximation to the camera's radiometric calibration; the images were not "flat-fielded" and we did not use the best dark current removal.
* We could not include all the phase angles that later became available.
Later analyses of some of these data, which included better calibration (especially flat-fielding), provided different results. The newer estimates of Uranus's planetary reflectance differ from the older estimates by as much as 8% in the clear filter, up to 17% in the UV filter, and up to 13% in the orange. Similar differences are seen in other filters and for Neptune. Wenkert and Friedson (2008) described the techniques used in these newer analyses (and proposed here).
Most importantly, these results cannot currently be reproduced, because the input data are not readily available in processed form.
"Quick-look" engineering data records (QEDRs) for the raw images are now available on the PDS imaging node website. We propose to reprocess all Voyager 1 Neptune and Uranus images. Processing will use the best calibrations to reprocess previously analyzed images and process data that were not previously analyzed. The steps are as follows.

1. We will convert the QEDRs to EDRs (units of DN), with VICAR labels and PDS 4 labels so that they will be readable by the community. We will archive all of them in PDS.
2. We will visually evaluate EDR images of dark space and those acquired with the shutter closed, for use as sources for dark current images. Those that meet our criteria will be used to determine dark current across the ISS-NA field of view, for various exposure durations.
3. Each EDR image of each planet will be evaluated for use as an input to determine planetary reflectances. These images will be checked for saturation and artifacts inside the planetary image/streak.
4. We will develop a pipeline to convert the EDRs to RDRs (units of I/F), using the best flat-field calibrations and the dark current calibrations developed from the images selected in Step #2. We will archive the results in the PDS.
5. Images deemed of sufficient quality in Step #3 will be analyzed (from RDRs) to determine the reflectance in each band at each phase angle of each full planet. The results will be published in the open literature and also archived (as higher-level products) in the PDS.

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Tim Glotch, Stony Brook University

Ultraviolet through mid-infrared optical constants of minerals and glasses relevant to planetary spectroscopic analyses (partial selection)

The proposed project will optimize VNIR optical constants code and convert it into a Python web-based application. This code will be the first publicly available radiative transfer code for the calculation of VNIR optical constants that explicitly allows for the inclusion of MIR reflectance data in the calculation VNIR optical constants. Furthermore, this code will be converted Python, an open-source computer language, and made available via GitHub, to facilitate its use by a broader subsection of the scientific community.