Planetary Data Archiving, Restoration and Tools 2018
Abstracts of selected proposals
(NNH17ZDA001N – PDART18)

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. 91 proposals were received in response to this opportunity. November 6, 2018, 16 proposals were selected for funding.
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Aneece, Itiya /USGS Menlo Park
Data Exploration, End-member Identification, and Spectral Unmixing with the Python Spectral Analysis Tool (PySAT)

1. Description of Goals and Objectives:
Past, present, and future planetary missions produce large spectral datasets, both in the form of point spectra (e.g. Curiosity s ChemCam, Mars 2020 s SuperCam, MER Mini-TES) and imaging spectrometer cubes (e.g. MEX s OMEGA, MRO s CRISM, Chandrayaan-1 s Moon Mineralogy Mapper). These data contain large amounts of information about the chemical and/or mineralogic composition of planetary surfaces. However, exploring these data to identify meaningful information can be challenging. The Python Spectral Analysis Tool (PySAT) is an open-source software library that has been developed with previous PDART support. A graphical user interface, focusing on preprocessing and multivariate regression has been one focus of development, while spectral parameters and analysis of imaging spectrometer data have been a parallel and complementary development path. In this project, we propose to expand PySAT by adding algorithms for data analysis and exploration, end-member identification, and unmixing. We will include algorithms that have been found to be useful in terrestrial remote sensing applications, those that have previously been used in planetary science, and newer methods that have yet to be applied to planetary data.

2. Description of Methodology:
Task 1: The first task is to incorporate techniques for identifying meaningful structure in spectral data by reducing data dimensionality. Included will be those algorithms that are commonly used in terrestrial applications, such as linear discriminant analysis (LDA), local Fisher discriminant analysis (LFDA), non-negative matrix factorization (NNMF), and minimum noise fraction (MNF), that will benefit the planetary science community. Unlike the more commonly used principal component analysis, LDA reduces dimensionality with the goal of increasing separability between classes (Li et al., 2018). LFDA preserves input data structure when reducing dimensionality (Bue 2014). NNMF works well for highly-mixed cases (Liu et al. 2016). MNF can also be used for noise removal (Houborg et al. 2016). Task 2: The second task is to incorporate end-member identification and unmixing algorithms into PySAT. For example, we will incorporate the commonly used pixel purity index (PPI) (Kodikara et al., 2016), N-FINDR (Thompson et al., 2010), the automatic target generation process (ATGP) (Ettabaa and Salem, 2017), and fast iterative PPI (Chang et al., 2017), leveraging the Python library pysptools. In addition, multiple end-member spectral mixture analysis (MESMA) (Gou

et al., 2015) and sequential maximum angle convex cone (SMACC) (Gilmore et al., 2011), are commonly used in planetary and terrestrial applications. For unmixing, we will include linear and nonlinear methods commonly used in planetary and terrestrial remote sensing, including non-negative least squares (Ramsey & Christensen, 1998), extended linear mixing model (Drumetz et al., 2017), multi-linear mixing model (Drumetz et al., 2017), and generalized bilinear model (Yang et al., 2018). Task 3: We will incorporate new methods from Tasks 1 and 2 into the existing graphical user interface to make them accessible for non-programmers. Information about improvements to PySAT will be disseminated at the 4th Planetary Data User s workshop and through publication in SoftwareX.

3. Description of relevance to the Planetary Data Archiving, Restoration, and Tools (PDART) program:
This proposal addresses the PDART solicitation to develop or validate software tools. We will be further developing the previously PDART-funded open-source PySAT software library to facilitate spectral data exploration and interpretation.

Bernath, Peter /Old Dominion University Research Foundation
Infrared Absorption Cross Sections for Planetary Atmospheres

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. It focuses on the spectra of small hydrocarbons and related molecules; of particular interest are the hydrocarbons ethane, propane, propene, and butane. 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, nitrogen and helium 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 and for some species a line-by-line analysis will be carried out. These data 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 are needed for example to support Juno and 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.

Bishop, Janice /SETI Institute
Providing Spectral Library Data to the PDS and CAT

The objective of this project is to provide a large collection of reflectance spectra and ancillary data of well-characterized geologic materials to the planetary community. These spectra are needed for scientists analyzing CRISM data of Mars, M3 data of the Moon, Dawn VIR data of Vesta and Ceres, VIMS data of Saturn s moons, and the OSIRIS-Rex OVIRS data of asteroid Bennu, as well as for spectroscopic studies of other planetary bodies. A large collection of spectral data files (at least 1000) containing reflectance spectra and multiple ancillary data products of minerals, mixtures and natural samples from the Bishop collection will be processed and posted for community use at the NASA Planetary Data System (PDS) and CRISM Analysis Tool (CAT) archives. The PDS is publicly available for all users and the data will be archived with all necessary information for using the data, as well as the ancillary compositional information and additional spectral files for each sample. The CAT is also freely available to download and use with ENVI for any interested user for planetary spectroscopy studies. Laboratory spectral data from the Bishop library will be selected for well-characterized samples that will be useful for interpreting spectral data of planetary bodies. The goal of this project is to increase the amount and quality of laboratory spectral data available for planetary science research and exploration.

DellaGiustina, Daniella /University Of Arizona
Synthesis of Global Color Mosaics of Asteroid (433) Eros

Objectives/Methods:
Color image and band-ratio composite products of asteroids have been used to understand surface composition, regolith grain size, and space weathering effects. Despite the scientific value of color composite products, very few have been delivered to the Planetary Data System (PDS) for NEAR MSI data from Eros. Of those available on the PDS Small Bodies Node, none provide global coverage. In part, this is due to the challenging nature of the NEAR MSI dataset, which experienced a wavelength-dependent degradation of the system point spread function due to hydrazine contamination on the optics of the imager.

To complete the set of spatially and radiometrically remediated MSI images, we will implement updated remediation techniques to recover the geometric and radiometric accuracy of MSI images in the 450, 550, and 1050 nm filters (which experienced the most degradation due to contamination) and coordinate with the PDS Imaging Node to archive these data. Using these remediated data, we will develop globally controlled mosaics for each MSI filter, from 450-1050 nm, and deliver these data to the PDS archive. To generate these mosaics, input images will be projected to the >3 million facet Gaskell (2008) shape model of Eros and photometrically corrected. Creating these products will require us to solve for the spacecraft position and orientation of the

individual MSI frames used in each map; this updated SPICE information will be included in our delivery to the PDS. Finally, we will produce and archive global band-ratio and composite maps using the photometrically corrected (30° incidence, 0° emission, 30° phase) and photogrammetrically controlled mosaics.

Enhancements to existing tools within the Integrated Software for Imagers and Spectrometers version 3 (ISIS3) are required to enable the objectives of this proposal. ISIS3 is a free, specialized, digital image processing software available through the U.S. Geological Survey s Astrogeology Science Center (USGS ASC). Improvements to ISIS3 will include:
-Updating the MSI ingestion application (msi2isis) and MSI camera model in ISIS3 for corrections and consistency to support generalized image processing within the software.
-Updating the ISIS3 SUMFILE ingestion tool (sumspice) to provide support for MSI data.
-Increasing the accuracy and efficiency of ISIS3 routines for projecting images to tessellated 3D shape models of irregular bodies.
-Submitting any tools or updates developed as part of this work to the public release of ISIS3.

Relevance to Planetary Data Archive & Restoration Tools:
This work will fundamentally improve the accuracy and usability of the NEAR MSI data from Eros. By archiving these derived products, we will enable future investigations of Eros as well as small body comparative science.

Dong, Chuanfei /Princeton University
A model database of unmagnetized planetary space environment with an interactive user interface

Goals and objectives: Unmagnetized planets, like Mars and Venus, are especially susceptible to atmospheric scavenging because the solar wind interacts directly with the upper atmosphere due to the lack of an intrinsic dipole magnetic field. The dynamics of these obstacles and the subsequent atmospheric escape are still a major area of research as they are critical aspects of (exo)planetary and atmospheric evolution. PDS and other PDS-equivalent archives have a plethora of in-situ observations made across solar system unmagnetized bodies, including Mars and Venus. But single point measurements, and even multi-point measurements, only provide a limited view of the upper atmosphere, solar wind interaction and plasma environment for unmagnetized bodies at a given point in time. Furthermore, the majority of solar system observations have taken place within the last 40 years, over which the solar cycle has varied considerably. By nature, understanding the global behavior of planetary upper atmospheres and their interaction with the solar wind under a variety of conditions is a modeling activity. It is, therefore, our goal to create a library database of results from unmagnetized planetary space environment models. The primary objectives of the proposed work are 1) to make a public model database from a large number of existing and new MHD model results and

2) to provide open-source software packages that can visualize and analyze the model database, including data-model comparisons.

Methodology: In recent years, simulations of unmagnetized body plasma interactions at Venus and Mars have played a key role in the interpretations of mission data (e.g. from PVO, VEX, MGS, MEX, MAVEN), and as a result, a significant number of MHD model results exist. We use this 'model data' base in the development effort - with its design appropriate for future extensions to other types of planetary environments (e.g. magnetospheres). We propose to create a public model database and open-source software packages for existing and new MHD results at Mars and Venus for a variety of conditions, including EUV, solar cycle, solar wind velocity and density, interplanetary magnetic field (IMF), season and extreme space weather events. Our strategy is to integrate advanced tools supported by the modern data science community for the delivering and interpretation of our simulation data. The main components of the integrated framework include i) a tag-based, highly searchable model database, ii) a web interface for flexible data query and fast, interactive 1d/2d/3d visualization using the open-source Bokeh and ParaViewWeb infrastructures, with physics-driven applets like data-model comparison, and iii) a user-end interface for data query and visualization with Python APIs. The integrated framework will also be extensible to enable comparison with external models (such as hybrid models) and/or user-defined model/observational data, etc. All datasets and tools will be open-source and publicly available via NASA's PDS Github site. The proposed work does not include hypothesis-based science, fundamental theoretical research, or instrument development.

Perceived significance: The proposed work is highly relevant to NASA's PDART program, as it would advance the current state of knowledge about unmagnetized (exo)planetary upper atmospheres and their interactions with the solar wind by providing a model database, and visualization and data analysis tools to compare to existing or future observations. The proposed database would increase the amount and quality of digital information available for planetary science research and exploration, and would provide accompanying software tools that would enable and enhance the interpretation of data from future scientific investigations. Additionally, the proposed database would augment science that directly addresses several of the planetary science strategic goals as outlined in the 2013-2022 decadal survey.

Ehlmann, Bethany /California Institute of Technology
A Global CTX Mosaic of Mars

We propose to generate and make publicly available a global, seam-corrected mosaic of Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) data, rendered at 5.0 m/px, registered to Mars Orbiter Laser Altimeter (MOLA) data. Once completed, this product will represent a factor of 400 improvement in spatial resolution over the next highest-resolution global mosaic, derived from 100 m/px THEMIS IR data. This product will incorporate voluminous feedback we have received from over 30 Mars scientists from a

range subdisciplines who have beta tested select regions, and from crowd-sourced feedback of our initial global beta product to be posted online later this calendar year.

Our automated pipeline prioritizes data heritage so that (1) users know the parent orbit and all metadata for every pixel in the mosaic, (2) they can instantly access pre-blended and raw versions of original orbits, and (3) all seams in the mosaic are mapped in an accompanying vector layer to avoid misinterpretation. To do this, we implement state-of-the-art non-destructive image processing techniques that are engineered to preserve all information from input data. This is a major advance over traditional, sequential image processing routines that destroy information during each step. We employ a modular approach by generating 4°x4° blended tiles that can be individually updated and replaced without having to regenerate the global product. Our full proposal will outline the suite of techniques to achieve a seamless global map and to fully register the mosaic to the only consistent global elevation map of Mars, derived from the MOLA dataset.

The pipeline we have developed has benefited greatly from detailed feedback we have received from over 30 Mars scientists, who have beta-tested regional products that we have created. To further improve our pipeline, we plan to release an initial global beta product by the end of 2018 to solicit feedback from an intellectually diverse cross-section of the Mars science and engineering communities. This version will have orbits blended together, but the 4°x4° tiles will not be blended together, due to current processing limitations and our desire to optimize the initial blending procedure that we have developed, both of which will be done in this PDART proposal. Feedback received will be incorporated into our blending pipeline for this project.

We will propose to complete and then archive and host the finished mosaic on servers that will be accessible to the global planetary science community and the public at large with mirrored availability in the NASA Planetary Data System. Individual tiles will be archived as GeoTiffs, and the seam-maps will be provided as vector-based shapefiles as well as preferred PDS formats, determined in consultation with the Geosciences node archivist. These data will be easily readable in all GIS desktop software (ArcGIS, QGIS, ENVI, Google Earth, etc.), as well as common command-line platforms (USGS ISIS, GDAL, etc.). Additionally, we will provide tiled versions of the completed mosaic in streamable forms for Google Earth (as a kml/kmz file) and for more analytical interfaces like ArcGIS, JMARS and QGIS (as a WMS mapserver). This will allow the community to use the mosaic without prohibitive download time or storage needs.

The NASA Planetary Data Archiving, Restoration, and Tools program is the natural element to facilitate this project, as it specifically requests proposals to produce higher-order data products. A global mosaic of CTX imagery is of clear value to the Mars science and exploration community in particular, the planetary science community as a whole, and the public at large.

Johnson, Jeffrey /Johns Hopkins University
An archive of Mars Science Laboratory ChemCam passive visible/near-infrared surface spectra

Science questions/Objectives:
Johnson et al. (2015) demonstrated that the MSL ChemCam spectrometers exhibit sufficient radiometric sensitivity in the 400-840 nm region to allow collection of surface spectral reflectance in passive mode, i.e., without using the laser portion of the laser-induced breakdown spectrometer (LIBS) instrument (cf., Wiens et al. 2015; Maurice et al. 2016). The unprecedented high spatial (0.65 mrad field of view) and spectral (<1 nm) resolutions of these measurements allow unique investigations of the spectral band positions, shapes, depths, and slopes of spectra collected of targets both near and far from the rover. Although variable surface dust can subdue spectral features in the 400-840 nm wavelength region, ChemCam passive spectra typically were acquired after the LIBS laser shots removed substantial amounts of dust. Also, the rover wheels disturbed soils and rocks, and drill activities provided freshly ground fines, all of which were less affected by dust. ChemCam passive spectra therefore provide the opportunity to investigate spectral variability related to minerals such as hematite, magnetite, ferric sulfates, nanophase (or partially crystalline) ferric oxides, and more ferrous minerals such as olivine and pyroxene (Johnson et al., 2015, 2016, 2017, 2018). Identification of these species helps constrain the mineralogy and crystallinity of iron-bearing minerals relevant to understanding the magmatic, erosional, aqueous, and aeolian history of Mars.

To provide these surface spectra directly to the planetary community, we propose to calibrate the existing ChemCam passive spectra raw data files available in the PDS (through mission Sol 1869) to both radiance and relative reflectance using algorithms developed by the PI previously (Johnson et al. 2015). We will develop and archive new software that incorporates these algorithms while providing options for users to alter specific calibration files or methods should they wish to investigate alternative techniques. The software and associated documentation (including a User s Guide) will be archived in the NASA GitHub site. For each spectrum, we will use information contained in the data headers and related ChemCam Remote Micro-Imager (RMI) and Mastcam images to provide metadata useful in understanding the spectrum acquisition (e.g., target name and type, exposure time, raster location), illumination conditions (local time, photometric angles, degree of target shadowing), and instrument conditions (detector temperature), as well as atmospheric opacity.

Implications/Significance:
By archiving ChemCam passive calibrated radiance and relative reflectance spectra in combination with the software algorithms used in their generation, the proposed work will directly address a need in the planetary science community for in situ, high spatial and spectral resolution visible/near-infrared data of Mars surface materials. The combination of flexible, well-documented calibration software and the production of calibrated spectra with supporting metadata will provide researchers a straightforward means to investigate either specific targets of interest or conduct comprehensive studies using thousands of individual spectra. The former will assist in documenting spectral

features associated with millimeter-scale surface targets, thereby adding constraints on the mineral diversity along the rover s traverse. The latter would be valuable in understanding spectral variability of larger surface geologic units, particularly when compared to orbital visible/near-infrared data sets (e.g., CRISM, OMEGA, HiRISE).

Malaska, Michael /Jet Propulsion Laboratory
Registered and modernized Callisto NIMS dataset

Hyperspectral data from the Galileo spacecraft s Near-Infrared Mapping Spectrometer (NIMS) represents an untapped resource of high value for assessing the surface properties and surface compositions of Jupiter s moon Callisto. This dataset will be useful for planning and comparison of future observations from spacecraft missions such as JUICE and Europa Clipper, as well as ground and space-based observations of Callisto s suface. The NIMS instrument recorded multiple high-resolution observations of Callisto, however the NIMS data available from the PDS are notoriously difficult to work with, and so only a limited number of these observations have been used for detailed analysis. One of the difficulties with the dataset is that precise georeferencing of the NIMS near-infrared dataset with Galileo Solid-State Imager (SSI) visible imaging, which is desirable for compositional terrain analysis, is difficult to achieve, as the instruments were not boresighted, and rarely performed simultaneous observations. As a result, there are discrepancies between the coordinates supplied in the original data products with respect to the modern USGS coordinate frame. In addition, not all NIMS observations were processed using the correct wavelength calibration.
The goal of our proposal is take the available highest-resolution (<20 km per pixel scale) NIMS Callisto observations, and deliver to the PDS (in PDS4 bundle format) recalibrated NIMS observations that have been registered to the USGS Callisto grid. In addition, we will also deliver intermediate products to the PDS as miscellaneous files. These files will be GeoTiff image and multiband GeoTiffs image files that can be directly read into commonly-used GIS and spectral analysis programs such as ArcGIS, QGIS, and ENVI. Our efforts will enable researchers to more easily access these datasets for research and analysis of Callisto s surface composition and geology.
Our proposed processing pipeline starts with NIMS and SSI data downloaded from the PDS that cover approximately the same area on Callisto s surface. We will convert the SSI data into .cub format and import it into ArcGIS (ESRI), and register it to the lower-resolution SSI-based USGS Callisto grid. We will take the NIMS data, recalibrate it, then import and register the data set to the higher-resolution SSI data set using the shorter wavelength NIMS data that overlaps with SSI wavelengths. We have developed a pipeline to produce Europa NIMS products and the Callisto pipeline will follow the same strategy. After registration of the datasets in ArcGIS, we will export the SSI and the NIMS datasets as separate GeoTiff files and associated world files. These files will be converted into PDS4 usable files, but the user-friendly GeoTiffs also saved into the PDS. We will generate two separate PDS4 bundles : SSI and NIMS and deposit them into the PDS.

Our proposal is relevant to Program Element Scope Section 1.2 Data Product Generation as we will take an existing dataset in the PDS (Galileo NIMS and SSI) and convert them to a higher-order product. The description of Section 1.3 Data Set Restoration and Archiving is also relevant, as one part of our proposed work is to recalibrate and restore the NIMS dataset. The data will be read from the PDS, manipulated using available software, and redeposited in the PDS in PDS4 format.

Meech, Karen /University of Hawaii, Honolulu
Cometary Observation Metadata Archive (COMA), an Interactive Science Portal for Primitive Solar System Objects

Science Goals & Objectives This project will use long-term comet and small body photometric archives to understand long- and short-term activity, and to explore the volatile distribution in these primordial remnants of solar system processes. The investigation of comet activity throughout the orbit is often difficult because of the long timescales and lack of uniform datasets. This data set will be of strategic importance for small body missions. Specific objectives include:

(1) We will develop the tools to ingest into a database and access 30 years of imaging data, ancillary information (observing logs, notes, ephemerides, observing geometry, conditions) and higher order data products as they are developed (light curves, composite images, results of modeling (dust-dynamical models and thermal models of activity) from the database.
(2) We will run all the data through our image pipelines to obtain astrometry, and photometry, as higher order data products to be stored in the database, and store this with orbital information at the time of observations.
(3) We will incorporate comet photometry from the ATLAS sky survey and the Comet Observation Database of amateur comet brightness observation pro-am website at the Institute for Astronomy, and will develop tools that will allow data from both databases to be queried.
(4) We will develop a suite of new tools to visualize the existing data, for example showing where along the orbit of a comet there exists data in the database, rotation light curves, etc.
(5) We will develop a web interface for our observing planning tool that will allow uses to select targets in need of observation and optimally plan the observations for any observing site.
(6) All tools and web access to the data products will be made publicly available.

Methodology Proposed Our team at the Institute for Astronomy has accumulated a ~2 TB data set of CCD imaging observations during the past 30 years. The data in this program were obtained on 1-10m class telescopes, and focuses on faint comets, Centaurs, TNOs and MBCs. Data for comet 9P/Tempel 1 are already in the PDS (under review), and we have funding to archive data from 1997-2011 into the PDS; the rest will be submitted under this program. We have also developed a large database to store the data and higher

order data products locally and we already have the computer server for this. We still lack the tools to systematically ingest the data, to create the ancillary products (photometry, astrometry, in addition to some higher order products), to query the database for these products from the web, and to visualize the data.

The ATLAS project at IfA is a system that will patrol the entire Hawaii night sky twice per night to look for hazardous NEOs. It will also secure observations of bright comets, which we will use to create a database of fully calibrated comet light curves. In a complementary effort, a team of observers at the Crni Vrh Observatory (0.6m telescope) has been conducting an intensive observing campaign of bright comets since 1989 (www.cobs.si). Like the American Association of Variable Star Observers, this service has attracted the amateur observing community, and there are currently ~130 members who actively report observations. We wish to link the two databases together to enable science investigations for comets over their orbits. We will also use this dataset as a test bed for development of data visualizations to be explored in a 3D Cybercanoe visualization facility being developed by CoI Jason Leigh.

Relevance to PDART Program This program supports generation of higher-order data products, archiving data sets and products, the creation of databases, and the development of software tools. We propose to develop tools to access data and create higher order data products from a 30-year database of CCD observations of comets, and to facilitate ingestion of any newly acquired data into the PDS.

Moskovitz, Nicholas /Lowell Observatory
A Next Generation Minor Planet Database

Comets and asteroids provide important clues about the origin and evolution of the Solar System. For over 20 years Lowell Observatory has maintained catalogs of orbital elements for all known minor planets. These asteroid (astorb) and comet (comorb) catalogs are actively curated and represent the current census of more than ¾ of a million minor planets in the Solar System. With NASA PDART support we have been working for the past two years to modernize the astorb database and associated system of software. This has involved modifying backend infrastructure, developing a new website (asteroid.lowell.edu), and adding physical properties (e.g. albedos, lightcurve periods, spectral types) to the database. This work is ongoing and will reach completion in mid-2019. From this work, we have identified a number of improvements that will further increase community access to the database and expand its capabilities. We propose here to develop new features that will build upon the astorb and comorb databases.

This work will consist of three primary components. First, we will incorporate into our system the open source, direct N-body integrator GENGA (Grimm & Stadel 2014) which is designed for GPU-based hardware. N-body integrators for minor planet orbits typically use CPUs and thus are limited to a handful of processing cores. GPUs have a much larger (~100x) number of cores, which makes them very well suited to parallelizing a large

number of simple floating point calculations like those needed for orbit integration. This software will facilitate efficient maintenance of our database and the creation of novel observational planning tools.

Our second major task will involve adding comets and interstellar objects to the database. For over 20 years comorb has only been used internally at Lowell, this will be the first time these data are made publicly available. We will augment our database to handle comets and complexities associated with their orbital and brightness properties. Folding comets into the astorb ecosystem will enable use of the observational planning tools on the project website.

Our third major task will involve building a bridge between the Lowell database and the JPL small-body orbit determination system. Since their inception the Lowell catalogs have served as independent calculations of orbital elements, regularly computed as new data become available. As the number of known minor planets has grown by orders of magnitude since astorb s inception and will continue to do so in the LSST era, maintenance will become increasingly challenging. This problem can be greatly ameliorated if we can outsource the initial computation of orbital elements. Fortunately, JPL produces the highest quality orbital elements in the world, are well prepared to handle the influx of objects from LSST, and have an API (Application Programming Interface) for access to their orbital elements. We will work closely with the Solar System Dynamics group at JPL to ingest their orbital elements into astorb so that we maintain all of our associated functionality while building long-term stability. In exchange for receiving orbital elements from JPL, we will provide them our curated physical properties database, which has been added to astorb during our first iteration of PDART funding. These physical properties will then be accessible through the JPL system. We will implement a Virtual Observatory (VO) interface to astorb, which will provide open public access to the database as well as facilitate the transfer of data to JPL.

The two main themes of this proposal are increasing access to the astorb and comorb data, and expanding their capability for future users. The tasks in support of these themes are directly in line with PDART objectives to (1) create a reference database to enable planetary science research and (2) to develop software tools that will enhance future science investigations.

Sava, Paul /Colorado School Of Mines
High resolution 3D imaging of SHARAD data

Recent 3D imaging of Martian polar ice caps using Mars Reconnaissance Orbiter Shallow Radar (SHARAD) data reveals details of complex internal structures, including layering unconformities, faulting, and previously unknown buried impact craters (Putzig et al., Icarus, 2017). 3D data volumes benefit greatly from custom processing similar to technology employed in terrestrial seismic imaging. The ultimate imaging goal is to provide the sharpest interior views that enable an improved understanding of the polar

depositional history by clearly resolving fine structures, allowing new age constraints from internal craters, and providing a firmer tie between layering and recent Martian climate history.

3D processing applied to date on SHARAD data only scratch the surface of the available imaging toolbox, and have been limited by practical considerations and software resources. We propose to take 3D SHARAD data processing to the next level, employing state-of-the-art technology capable of increasing the imaging accuracy and resolution. We plan to update raw data preprocessing with technology recently developed by members of our team to yield an optimized 3D data volume, and generate new 3D high-resolution image volumes for both Planum Boreum and Planum Australe.

Currently, conventionally processed SHARAD 2D radargrams are binned and interpolated at the orbital level, followed by downward continuation to the vicinity of the ice cap (Foss et al., The Leading Edge, 2017). This procedure limits the obtainable imaging resolution, since bin sizes (475m x 475m) are based on the radargrams, which are sampled coarser than the desired resolution needed by the complex interior structures. Moreover, imaging was performed using algorithms strictly appropriate for laterally invariant media, which sacrifice accuracy for speed.

We plan to modify the processing sequence as follows:

1. Re-datum the SHARAD data from orbit directly to the topography defined by the Mars Orbital Laser Altimeter (MOLA), without subsampling or interpolation. This better preserves data integrity, facilitates higher resolution, and accounts for the SHARAD antenna pattern.

2. Correct for traveltime ionospheric distortions on the MOLA surface, instead of doing so at the orbit level. This reduces computing costs and increases the reliability of traveltime calculations, without requiring cross-correlation between data acquired on intersecting tracks.

3. Focus the data relocated to the MOLA surface using imaging techniques that fully account for lateral variation of the radar velocity, e.g. reverse-time migration (RTM). This advanced imaging technology improves both subsurface positioning of radar pulses and vertical resolution.

4. Remove track-spacing artifacts from the migrated images using inversion techniques, e.g. least-squares RTM. This technique eliminates the point-spread function of the acquisition array and could impose sparsity constraints on the image, further enhancing its resolution.

5. Use wavefield tomography to focus diffractions generated by sharp structural features, as a means to enhance the velocity model used for 3D wavefield imaging. This step constrains spatial velocity variation, leading to improved lateral and vertical resolution in the image volumes.

The proposed methods here leverage imaging technology recently proposed by the PI (Sava & Asphaug, Advances in Space Research, 2018a,b).

Our team includes the Director of the Center for Wave Phenomena (CWP) at the Colorado School of Mines (CSM), with many years of experience developing and applying the proposed imaging techniques. Software needed for the project exists or will be developed at CSM and made available to the community as open-source (www.ahay.org). The Center computing resources will be made available at no additional cost to the project. Our co-Investigators have extensive experience with SHARAD 3D processing and similar applications to terrestrial seismic data.

Seelos, Frank /Johns Hopkins University
Completing the CRISM TER/MTRDR PDS Archive Restricted Gimbal Angle Hyperspectral Targeted Observations

The Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) team is delivering to the Planetary Data System (PDS) two suites of high level data products and visualizations that present the surface spectral information content of CRISM hyperspectral targeted observations with systematic corrections for atmospheric gas absorptions, aerosol scattering, photometric effects, and instrument artifacts. The correction of these effects makes the data much more accessible to the Mars science community as compared to the CRISM PDS standard product Targeted Reduced Data Records (TRDRs - calibrated spectral radiance and reflectance). Targeted Empirical Records (TERs) contain the fully corrected, full spectral range data in sensor space, and the Map-projected Targeted Reduced Data Records (MTRDRs) are map projected TERs with bad bands and spatially disconnected frames removed. Each product suite includes corrected I/F data, spectral parameter maps, and easily viewed browse versions of the data. The MTRDRs are projected using MRO standards and are GIS-ready with an ESRI coordinate system string in each product header.

CRISM targeted observations use image motion compensation to enhance SNR. The requisite gimbal motion introduces continuous variations in the emission and phase angle geometry with attendant variations in atmospheric path length and aerosol scattering across the scene. For the first six years of orbital operations CRISM targeted observations consisted of a high spatial resolution central scan and an accompanying set of Emission Phase Function (EPF) scans - spatially overlapping, reduced spatial resolution images acquired before and/or after the central scan using the full angular range of the gimbal. The extended angular sampling provides the basis for a key component of the TER/MTRDR data processing - the Empirical Geometric Normalization (EGN) procedure - which makes use of the EPFs to characterize and correct structure in the central scan traceable to the continuously varying geometry. Beginning 10/01/2012 the CRISM gimbal range has been restricted to an asymmetric portion of the central scan due to a hardware malfunction. Targeted observations acquired since do not have

accompanying EPFs and do not meet the prerequisites of the EGN procedure. The reduced gimbal range observations released to the PDS (acquired through 11/08/2017) now compose ~24.3% of the CRISM targeted observation archive.

The proposed activity entails: (1) The development, testing, and implementation of a bootstrap approach to an EGN-like correction for targeted observations that do not have accompanying EPFs. The development concept is to establish a look-up table of correction forms from the archive of TER/MTRDR-processed observations. The most appropriate correction form for a given EPF-less observation will be identified according to discriminating characteristics such as atmospheric state, phase angle range, season, solar azimuth angle, and geographic location. (2) The generation of the TER/MTRDR data product suite for each EPF-less observation for which an appropriate correction form can be established. (3) The validation of each resultant product set using the existing CRISM PDS special product release review system. This review and commenting system allows inadequately corrected products to be intercepted and quality flags and comments to be recorded for each product. (4) The PDS delivery of the validated product set as an augmentation of the existing CRISM TER/MTRDR archive curated at the PDS Geosciences Node.

The proposed CRISM data processing development effort and data product generation, validation, and PDS delivery are relevant to the PDART program as the products incorporate higher order spatial and spectral corrections and information content visualizations that will improve the accessibility and scientific utility of the CRISM hyperspectral targeted observation data set.

Stack Morgan, Kathryn /Jet Propulsion Laboratory
Preparing a USGS Geologic Map of the Northeast Syrtis and Jezero Regions of Mars

The northwest Isidis region of Mars hosts ancient terrains and diverse orbital mineralogic signatures. Geologic, stratigraphic, and mineralogic observations in this area have contributed towards fundamental Mars science and helped establish the paradigm of abundant water on early Mars [e.g., Bibring et al., 2006]. The NW Isidis area has hosted several highly ranked landing site candidates for the Mars Science Laboratory (MSL) mission and hosts two Mars 2020 landing site candidates: Northeast Syrtis and Jezero crater. Both of these locations provide compelling evidence for past habitable environments, but at the surface (Jezero) and in the subsurface (NE Syrtis) despite similar materials observed at both sites. A USGS geologic map of this important region would greatly enhance future scientific investigations by providing a regional framework in which to interpret local-scale orbital or rover observations. Previous maps for NE Syrtis [Bramble et al., 2017] and Jezero [Goudge et al., 2015] have different spatial extents and map scales and a continuous of this important NW Isidis area has yet to be produced.

Objective:

We will produce a USGS geologic map spanning the NE Syrtis and Jezero regions (1x1 degree area). The map will be constructed at a 1:20,000 Digital Mapping Scale on a CTX basemap and printed at a USGS Publication Map Scale of 1:75,000. Previous geologic maps cover only portions of the proposed map area and are different scales of 1:30,000 [Goudge et al.] and 1:1,000-5,000 [Bramble et al.]. We demonstrate that our proposed map will capture the geologic units in this area and improve on these previous mapping efforts.
We propose a two-year plan to publish this regional map before Mars 2020 lands in early 2021. During the first year, we will prepare a compliant map package for USGS review. During the second year, we will work with the USGS to expedite map review and publication prior to the Mars 2020 rover landing.

Significance:
The resulting map will be a valuable and timely resource for the Mars community, as it will support future orbital investigations and landed missions in this region and is immediately relevant for Mars 2020.
1) This map will provide broad geologic context for orbital or rover investigations. This map will also link geologic materials at both NE Syrtis and Jezero for the first time. Though NE Syrtis and Jezero are interpreted to represent different habitable settings, similarities between units at the two sites have been observed.
2) The mapped geologic units could serve as proxies for associated mineralogic composition in areas where there is no orbital spectroscopic data. This map will be extremely valuable for orbital investigations, as the geologic units here are strongly correlated with particular mineral compositions [Bramble et al., 2017], but this region has incomplete coverage of orbital mineralogic data (e.g., CRISM).
3) The production of a geologic map following the standardized USGS framework will allow determination of chronostratigraphic ages for these units from crater-count ages and comparison with regional stratigraphy in previous USGS maps.
Knowledge of this area is valuable for future investigations, including but not limited to Mars 2020. Even if the Mars 2020 mission does not land at either NE Syrtis or Jezero, this region has been of high interest to the Mars community during the past decade and is likely to be the focus of future investigations of this region, either by orbital studies or landed missions.

Relevance to PDART:
This work will produce a geologic map (a new high-order data product) that will enhance future orbital studies and landed missions. This work is not science hypothesis-driven and is not responsive to the Mars Data Analysis Program. This work is also not suitable for Mars 2020 project funding, as the proposed map is more regional in scale than landing ellipse maps that have been funded by previous missions (e.g., MSL).

White, Oliver /SETI Institute
A Global Geologic Map of Pluto at 1:7M Scale

Objectives:
We propose to use established geologic mapping techniques set by the United States Geological Survey (USGS) to produce a global geological map of Pluto at the 1:7M scale. Following its Pluto flyby in 2015, NASA s New Horizons spacecraft has returned high quality images that reveal an unexpectedly diverse range of terrains, implying a complex geological history. Surface renewal is ongoing, as demonstrated most compellingly by the nitrogen ice plains of Sputnik Planitia. Pluto s geological provinces are often highly distinct, and can exhibit disparate crater spatial densities. The geology displays evidence for having been affected by both endogenic and exogenic energy sources (including internal heating and insolation/climatic effects), and its complex nature is likely a consequence of combinations of these influences affecting the surface to varying degrees on localized scales. The global geological map of Pluto that we propose to make is the obvious and highly necessary tool that is required for future planetary science researchers to resolve and rationalize the bewildering complexity of Pluto s surface, and to address the fundamental issues of exactly which processes have been influential in shaping it, and when and where they have been active. The primary deliverable of this effort will be a Scientific Investigations Map (SIM) published through the USGS, enabling dissemination throughout the scientific community and use in future scientific analysis.

Methods:
Geologic mapping is a powerful analytical tool that places observations of surface features into their stratigraphic context in order to develop generalized geologic timescales that provide a sequence of events and responsible processes shaping the evolution of planetary surfaces. Our 1:7M scale global geologic map will cover more than 75% of Pluto s surface area. This mapping scale will allow characterization of small features of interest on the well resolved encounter hemisphere (covering ~50% of Pluto s surface area, and imaged at 890 m/pixel or better), while only a handful of undivided units will be defined for the poorly resolved anti-encounter hemisphere. Existing mapping of Sputnik Planitia and Wright Mons by PI White and Co-I Singer will be reviewed and updated onto the latest base map. All of the New Horizons images required to construct the base map are currently available on the Small Bodies Node of the PDS. Mapping will be performed in ArcGIS, and will follow the standard principles of the mapping of extraterrestrial bodies as outlined in the 2018 Planetary Geologic Mapping Protocol and references therein. To aid in our definition and interpretation of mapped units, we will construct 3D stereo anaglyphs to visualize surface topography, and will make use of published surface composition maps. Once geologic units are mapped, their relative ages will be determined from measured crater densities and observed stratigraphic relationships. GIS and PDF versions of the completed SIM will be made freely available for download at the USGS Publications Warehouse.

Relevance:
According to ROSES Appendix C.7, the PDART program solicits proposals to generate higher-order data products and aims to increase the amount and quality of digital information and data products available for planetary science research and exploration . The creation of a global geologic map of Pluto will provide an invaluable resource for a wide array of future scientific investigations of the dwarf planet. The creation of this geologic map is not part of a hypothesis-based investigation, although a small amount of data analysis and interpretation will be required as part of the mapping process and definition of the geologic history (e.g., crater measurements and age determination, assessing relative ages of materials, etc.). Therefore, the proposed work is more appropriate for PDART than NFDAP.

Williams, David /Arizona State University
Completing the Io Database: An Example of a Planetary Spatial Data Infrastructure

As part of my Outer Planets Research (OPR) Program-funded global geologic map of Io (http://pubs.usgs.gov/sim/3168/), I began construction of a digital Io database. This database, built in ArcGIS" on top of the digital GIS project containing the geologic map shapefiles and the combined Galileo-Voyager global mosaics produced by the USGS for that project, was intended to become a digital archive of all useful Io data collected during and after NASA s Galileo Mission to Jupiter. Since the geologic map was completed and published in 2011, we have been adding additional datasets to the database, including: 1) adaptive optics-derived, Earth-based telescopic maps of Io s hotspots produced by Imke de Pater and her colleagues, stereo digital terrain models (DTMs) of Io produced by Oliver White and Paul Schenk, regional scale Galileo Solid State Imager (SSI) mosaics and derived geologic maps published by myself and colleagues in peer-reviewed journals, hot spot power and temperature information derived from various databases, and model results of interior heating derived from the global map by Christopher Hamilton et al. However, since the Io grants have long ended, we lack the time and funding to complete the database, and make it a truly useful product by hosting it on a platform that will enable wider community access.

Thus, the purpose of this 1-year proposal is to request funds to complete the Io database and make available to the wider planetary community through the PDS and through Arizona State University s JMARS (Java Mission-planning and Analysis for Remote Sensing) platform. The concept is to have all useful Galileo-based and post-Galileo-derived data of Jupiter s volcanic moon Io organized in a GIS platform, where all of the data are spatially co-registered. This would enable easy study of specific volcanic features across a variety of data sets. Furthermore, with the inclusion of post-Galileo hot spot and temperature data from Earth-based telescopes and the February 2007 New Horizons flyby, the temporal evolution of specific volcanic centers can be traced as well. With all of the available Io data collected in one database, this product would serve as a

key component for an Io Planetary Spatial Data Infrastructure (PSDI). NASA s Mapping and Planetary Spatial Infrastructure Team (MAPSIT), the NASA advisory group chartered to oversee cartography and planetary spatial data issues across the Planetary Science Division, is currently developing a roadmap and advisories for all NASA advisory or assessment groups on the development of PSDIs for all of the solid-body planets, moons, and small bodies that have been or will become targets of NASA planetary missions. Thus, the product of this work, both a ArcGIS" and JMARS-based Io database, would not only 1) serve as a tool to conduct future Io research and investigate comparison of activity at specific volcanic centers, as well as plan observations for future Io missions; but also 2) serve as an example of one approach to developing PSDIs for geologically interesting targets in our Solar System.

Funding is requested to support time for PI Williams to review Io data sets and the final co-registered database, for Co-I Moses Milazzo to reprocess the Io SSI image mosaics in ISIS3 and reproject them using the control point network made for the global map, for use in our database, for ASU GIS Specialist David Nelson to complete the database in ArcGIS", and for Co-I Scott Dickenshied to adapt the GIS database into JMARS format.

The proposed work is relevant to the goals of the PDART program, specifically to produce higher-order data products that will enhance the scientific return from data acquired by NASA missions (in this case, Voyager and Galileo missions, as well as NSF-funded telescopic studies of Io).

Zou, Xiao-Duan /Planetary Science Institute
Improved SPICE Data and Archival of Cometary Mission Data

Objectives:
This project will update the SPICE data and archive geometric backplane data for the visible images (geometry information) of all comets (67P, 19P, 81P, 9P and 103P) imaged by Rosetta/OSIRIS-NAC, Deep Space 1/MICAS-VISCCD, Stardust/NAVCAM and Deep Impact/ITS/MRI/HRIV. Along with these two kinds of product, we will also add supporting modules in ISIS3 to better support the image analyses from all these missions and provide the community with ISIS3 scripts (archived in USGS Astro/ISIS3) for calculating backplane data (for Rosetta OSIRIS-WAC and NAVCAM). Currently none of the comet mission datasets provide pixel-wise geometric backplane data (incidence angle, emission angle, phase angle and cometocentric coordinates). The current versions of the ephemeris (SPICE) data of all these missions (Deep Space 1, Deep Impact, EPOXI, Stardust, Stardust-NExT and Rosetta) do not support sub-pixel precision registration between the shape model and all images. In other words, scientists who need to calculate the observing and illumination geometry for modeling and mapping purposes have to go through tedious and redundant processes.

Methods:

With our image processing tools, we will register the shape model precisely to all images to produce geometric backplanes with sub-pixel spatial precision. We will calculate the X and Y offsets and central rotation from the spacecraft position and pointing, and correct for it based on image registration. For the Rosetta mission, we will use the relative offset and rotation we derived from OSIRIS-NAC images to update the CK kernels. For other missions, we will use the offsets and rotation to correct the SPICE data (CK and/or SPK) for spacecraft and comet data using bundle adjustment processes. The backplane data and updated SPICE data will be archived to the PDS Small Bodies Node (SBN) and PDS NAIF for scientific analyses by the broad community.

Significance:

The precisely registered backplane data will greatly accelerate the scientific analysis that requires measurements of geometry, including photometry, spectroscopy, geomorphology and photogrammetry, etc. The improved SPICE kernels will be beneficial for all sciences that require accurate locations and pointings of the spacecraft, such as mass (density) estimates, shape model improvements and measurements of the orbit wobbling of the comets, and creation of cartographic maps.

The Rosetta data archive has just been completed in the PDS, and many scientists need the geometry data for their analyses. With this work, we are saving them the efforts to configure SPICE, render the huge 44 million facets shape model and go through a large amount of redundant and tedious work for spatial registration. With the right team and the right tool, we ensure the archival of the backplane data with the best geometry accuracy based on best currently available shape model and the tested controlled registration quality (sub-pixel). For other previous comet missions, the ISIS3 supports and updated SPICE will help the community with access to improved geometric data, and enable many new research opportunities. We also substantially simplify the process of revisiting the datasets from historical cometary missions.

Relevance to PDART:

The proposed work is relevant to the Planetary Data Archiving, Restoration and Tools (PDART) program as we will restore and archive datasets for use by the community; we will produce new data products to be submitted to the PDS, thereby increasing the amount and quality of data products that enhance future scientific investigations. The proposed archive holds relevance for all the comet missions as well as a future comet mission. The datasets would boost science and future proposals related to Rosetta and other comet mission data and push more revisiting study on the historical mission data. Prompt availability of this data, made possible by this proposal, provides efficient and accurate analysis of comet data.