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Monday, June 8, 2015

9:00 a.m.	Humphreys	Archiving Planetary Data
10:50 a.m.	Humphreys	PDS4: The New Planetary Data System
11:20 a.m.	Agassiz	Lunaserv Display
1:20 p.m.	Humphreys	PDS: Tools and Services
3:20 p.m.	Humphreys	Planetary Mission Data Archives, Tools, and Services I
5:00 p.m.	Humphreys Foyer	Poster Session: Planetary Data Archives, Products, Tools, and Services

Tuesday, June 9, 2015

9:00 a.m.	Humphreys	Geographic Information Systems for Planetary Science
10:40 a.m.	Humphreys	Software and Tools for Planetary Data Access and Analysis I
1:20 p.m.	Humphreys	Software and Tools for Planetary Data Access and Analysis II
3:00 p.m.	Humphreys	Demo and Hands on Training: APPS
3:00 p.m.	Humphreys	Demo and Hands on Training: Marsviewer
3:00 p.m.	Agassiz	Demo and Hands on Training: NAIF
3:00 p.m.	Fremont	Demo and Hands on Training: LROC

Wednesday, June 10, 2015

9:00 a.m.	Humphreys	Topics in Planetary Cartography and Research
10:40 a.m.	Humphreys	Planetary Geologic Mapping and Topographic Modeling
1:20 p.m.	Humphreys	Online Data Access, Tools and Services for Planetary Scientists
1:20 p.m.	Agassiz	Demo and Hands on Training: ISIS
3:20 p.m.	Humphreys	Planetary Mission Data Archives, Tools, and Services II
4:00 p.m.	Humphreys	Demo and Hands on Training: Python for Planetary Science Applications
4:00 p.m.	Fremont	Demo and Hands on Training: ArcMap
4:45 p.m.	Fremont	Demo and Hands on Training: QGIS

Thursday, June 11, 2015

9:00 a.m.	Humphreys	Planetary Data Archiving and Access: The Future
10:40 a.m.	Humphreys	Planetary Data Facilities and New Archives

Print Only

Print-Only Abstracts

Demonstrations of New SPICE Capabilities C. H. Acton[1], B. V. Semenov[1] N. J. Bachman[2], and E.D. Wright[1],
[1]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena CA, charles.acton@jpl.nasa.gov.

Introduction: The Navigation and Ancillary Information Facility (NAIF) provides NASA's space science enterprise an information system named SPICE, comprising both data and software, used by scientists to plan observations and to analyze the data returned from those observations. SPICE data include items such as solar system body's ephemerides, sizes, shapes and orientations; spacecraft trajectory and orientation; instrument pointing and field-of-view geometry; reference frame (coordinate system) specifications and parameters needed for time conversion capabilities.

Since the time of the last Planetary Data Workshop NAIF has released two new tools: **WebGeocalc**, a Graphical User Interface to a SPICE geometry engine, and **Cosmographia**, a SPICE-enabled data 3D mission visualization tool. NAIF has also greatly enhanced a **Digital Shape Kernel** subsystem, useful in providing observation geometry information based on high-fidelity models of target bodies.

In parallel to the 2nd Planetary Data Workshop NAIF will offer a SPICE class illustrating how these new capabilities may be used.

POW AND MAP2: JOB MANAGEMENT AND ADVANCED PROCESSING. Scott W. Akins, T.M. Hare, R.M. Sucharski, M.S. Bailen and L.R. Gaddis. U. S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ, 86001 (sakins@usgs.gov).

Introduction: In July of 2013, the USGS Astrogeology Science Center publicly released a tool called the Map Projection (on the) Web Service (POW). This free online service transforms Planetary Data System (PDS) Engineering Data Record (EDR) image files supported by the Imaging Node to science-ready, map-projected images [1] (***Figure 1***). In March of 2014, Map-A-Planet 2 (MAP2) [2] was released to provide similar functionality to POW for higher-level or derived map products to allow for user-defined map projections and band math calculations. POW and MAP2 use PDS Imaging Node tools (PILOT, UPC [3, 4], and the USGS Astropedia data catalog [5]) to locate image data products and enable the user to select and submit images to be projected. This process uses Astrogeology's image processing package called the Integrated Software for Imagers and Spectrometers (ISIS, currently in version 3) [6]. Since the public release of these two services, we have had over four hundred users register and the system has processed thousands of images (*432 users; 1638 POW, 543 MAP2 jobs).*

Relevance: To make PDS EDRs useful for science analysis, they must be radiometrically calibrated and then map-projected [7]. While some instrument teams deliver map-projected data, these products may not be in the most useful projection for the region studied. POW provides users with calibrated cartographic images and MAP2 provides derived data products. Both services provide map projection and processing to create derived data products that can be used readily for geologic mapping, change detection, merging of dissimilar instrument images, analysis in a Geographic Image System (GIS) and use in a host of other scientific applications (e.g., ArcMAP, ENVI, Matlab, JMARS, QGIS, Opticks, etc.).

POW is dependent on ISIS and the instruments it supports [6]. As new instruments are added to ISIS, POW will also increase the number of supported instruments. Currently, instruments supported in POW include:

- Cassini Imaging Science Subsystem (ISS) and Visible and Infrared Mapping Spectrometer (VIMS)
- Clementine Near Infrared (NIR), Ultraviolet and Visible (UVVIS), High Resolution (HIRES)
- Galileo Solid State Imaging (SSI)
- Lunar Reconnaissance Orbiter Wide Angle Camera (WAC), Narrow Angle Camera (LROC-NACL, LROC-NACR)
- Mariner 10 vidicon cameras (VID A, VID B)
- Mars Express High Resolution Stereo Camera (HRSC)
- Mars Global Surveyor Mars Orbiter Wide Angle Camera (MOC-WAC), Narrow Angle Camera (MOC-NAC)
- Mars Reconnaissance Orbiter Context Camera (CTX)
- Messenger Mercury Dual Imaging System (MDIS-WAC, MDIS-NAC)
- Mars Odyssey Thermal Emission Imaging System (THEMIS-IR, THEMIS-VIS)
- Viking Orbiter 1 & 2 vidicon cameras (VIS-1B, VIS-2A, VIS-2B)
- Voyager I & II Imaging Science Subsystem (ISS) vidicon cameras (NAC-1, NAC-2, WAC-1, WAC-2)

Learning Tool: While ISIS3 is free to the public, it can be a difficult toolset to learn. Currently, ISIS must be installed on a UNIX platform (e.g., Linux or Mac OSX) and requires the user to be familiar with UNIX operating system commands. POW and MAP2 allow researchers to make use of a wealth of PDS science data without having to install or learn how to run ISIS. Users also benefit from a validated data processing pipeline as defined by USGS and the instrument teams. This service can be used as a learning tool or an introduction to ISIS because a detailed log of the ISIS commands and their settings is provided along with the processed data products.

Using the POW front-end, a user is allowed to 1) select and submit a list of up to 50 PDS EDR images. Both the POW and MAP2 processing interfaces enable a user to 2) define an output map projection and its parameters (e.g., Polar Stereographic, Sinusoidal), 3) define the output bit type (8, 16, or 32 bit), and 4) select an ISIS or PDS output format or a geospatial format such as GeoTiff, GeoJPEG2000, PNG, or JPEG. Conversion to output image formats are completed using the Geospatial Data Abstraction Library (GDAL), which passes all cartographic information into the output format [7].

Improvements to POW/MAP2: The following improvements to POW and MAP2 are in development and will be available to users through the existing POW/MAP2 interfaces.

Reuse Processing from Templates or Prior Jobs: This enhancement will provide the option in both interfaces to reuse settings from previously run jobs and from recommended templates provided by the USGS. For example, there will be a template defined for GIS users which will select an optimal map projection and output format or another template which will stage files for further ISIS processing. Once settings are defined from a previous job, the user can refine them to correct a problem or improve on previous processing requests.

Selectable Backplanes: A new option for POW processing will be to select a backplane of the EDR data products, such as the incidence angle or phase angles, as the source for the derived data product.

Tonal Matches and Photometric Steps: POW processing will include new photometric correction steps, image equalization and new stretches to create more visually uniform data products from the products submitted. ISIS also supports the capability to tonally match multiple images to each other. This is accomplished using photometric corrections and/or pure statistical equalization methods. Both methods are especially useful for minimizing image seams in a mosaic.

Simple Mosaics of POW Images: A new feature for POW processing requests will be to have the individual images combined into a derived uncontrolled mosaic. Unfortunately, EDR data typically are geometrically referenced to a planetary surface only as well as the spacecraft pointing allows. Depending on the instrument and spacecraft, each image still could have meter to kilometer spatial offsets between adjacent images. Because ISIS3 continues to add more robust methods for automatically controlling images to each other, POW will be able to take advantage of these ISIS methods along with any improvements to SPICE to enhance the registration of delivered images. Our goal is to allow users to quickly and easily build seamless image mosaics from supported PDS image products.

Acknowledgments: This project was supported by NASA's PG&G Cartography Program and the PDS Imaging Node. To use POW/MAP2, please create a login on: http://astrocloud.wr.usgs.gov/

References: [1] Hare, T.M. et al., (2013), LPSC 44, abstract #2068. [2] Akins, S.W. et al., (2014), LPSC 45, abstract #2047. [3] Akins, S. W. et al., (2009), LPSC 40, abstract #2002. [4] Bailen, M.S. et al., (2013), LPSC 45, abstract #2246. [5] Bailen, M.S. et al, (2012), LPSC 43, abstract #2478. [6] Keszthelyi, L. et al., this volume. [7] Hare, T.M., et al., (2007), LPSC 38, abs #2364.

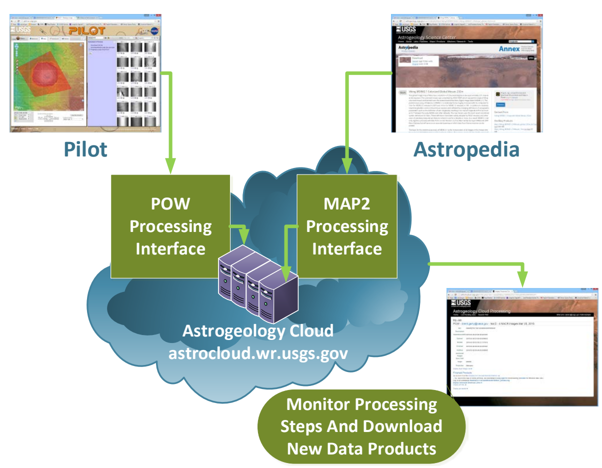

Figure 1. Simple graphical workflow for POW and MAP2.

CHEMCAM DATA ACCESS, PROCESSING, AND INTERPRETATION R.B. Anderson[1], K. E. Herkenhoff[1], R.C. Wiens[2], S.M. Clegg[2], O. Forni[3], J. Lasue[3], A. Cousin[3], O. Gasnault[3], D. Delapp[2], N. Lanza[2], D. Blaney[4], [1]USGS Astrogeology Science Center, Flagstaff, AZ (rbanderson@usgs.gov), [2]Los Alamos National Laboratory, Los Alamos, NM, [3]Institut de Recherche en Astrophysique et Planétologie, Toulouse, France, [4]Jet Propulsion Laboratory

Introduction: The ChemCam instrument on the Curiosity rover uses Laser-Induced Breakdown Spectroscopy (LIBS) to analyze targets up to ~7 m from the rover, collecting atomic emission spectra (240-850 nm) from the laser induced plasma that contain diagnostic emission lines of all major and some minor and trace elements in the sample. The laser is co-boresighted with a Remote Micro-Imager (RMI) for high-resolution (19.6 μrad/pix) imaging. ChemCam has collected >210,000 LIBS spectra and >4200 images on Mars.

The martian environment is ideal for LIBS because the low atmospheric pressure (5-7 Torr) results in a large, bright plasma spark [1]. LIBS is most sensitive (5-100 ppm) to elements that are readily ionized (e.g. alkali and alkali earth metals), and least sensitive (0.1-3%) to nonmetals and halogens.

LIBS Data Processing: Raw ChemCam LIBS spectra must be pre-processed before geochemical analysis [2, 3]. For each active LIBS spectrum collected, an accompanying spectrum is collected without the laser. This "passive" or "dark" spectrum can be subtracted from the LIBS spectrum to remove the effects of ambient light and absorption lines in the solar spectrum. Noise and continuum removal are both accomplished using an undecimated wavelet transform to identify high- and low-frequency signals in the spectra [2, 3]. The continuum in ChemCam LIBS spectra is related to Bremsstrahlung and ion-electron recombination in the plasma and is distance dependent, so continuum removal also partially corrects for distance effects.

An instrument response function and geometric factors are used to convert the spectrum from counts to photons [2, 3]. Normalization to total observed intensity, either by spectrometer (i.e. the sum of the full spectrum equals 3) or across all three spectrometers (i.e. the sum of the full spectrum equals 1) provides an additional correction for distance effects [2, 3].

Wavelength calibration and resampling of each-spectrum is crucial, given the narrow width of atomic emission lines. Spectra from a Ti calibration target on the rover are used to provide a temperature-dependent, channel-by-channel wavelength calibration [2, 3].

Qualitative Data Analysis: ChemCam LIBS spectra contain 6144 spectral channels and hundreds of spectral lines. To aid in identification of emission lines in LIBS spectra (Fig. 1), the ChemCam Quick Element Search Tool (C-QuEST) is available at [3], and can be used to search both the NIST spectral database and a database specific to LIBS spectra collected under Mars-like atmospheric conditions.

Data reduction methods are useful to analyze large spectral data sets and visualize spectral similarity. These methods include Principal Component Analysis (PCA), which reduces high-dimensional data to a lower number of dimensions by identifying axes ("components") corresponding to directions of maximum variation in the n-dimensional data cloud, and Independent Component Analysis (ICA) which is similar to PCA, but seeks to identify components that are statistically independent. ICA has the advantage that each component tends to correspond to a single element, so that each ICA score can serve as a qualitative proxy for signal strength from the corresponding element.

ICA or PCA scores are often used as the input to classification algorithms. Many algorithms can be used, including unsupervised (e.g. hierarchical clustering, K-means clustering), and supervised methods (e.g. Soft Independent Modeling of Class Analogy (SIMCA), PLS Discriminant Analysis (PLS-DA)). [e.g. 3,4,5,6,7]

Quantitative Data Analysis: ChemCam LIBS spectra can be used to determine quantitative abundances of elements of interest. For minor and trace elements, the ChemCam team uses "univariate" calibration [3,8,9], while concentrations of major elements are calculated using "multivariate" methods [2,3].

Univariate Calibration: This method uses the strength of a single emission line to predict the composition of the corresponding element. This method typically uses peak fitting to isolate individual emission lines within fully processed "cleaned calibrated spectra" (CCS). Peak areas can then be plotted against the known composition of the eight geologic ChemCam calibration targets onboard the rover and a calibration curve can be determined. Ratios of peak areas can also be used and help mitigate differences in line intensity on different target types. Advantages of univariate calibration are its simplicity and its independence from terrestrial measurements (i.e., it is based entirely upon spectra collected by the flight instrument under martian conditions). However, univariate calibration cannot correct for "matrix effects": factors that can cause an element's emission line strength to vary independent of elemental concentration [2,3,6].

Multivariate Calibration: Multivariate methods make use of the entire spectral range or a significant portion of it, rather than an individual emission line, to develop a regression model relating the spectrum to a chemical composition. By making use of all available information in this manner, multivariate methods can partially correct for matrix effects [6]. The disadvantage of multivariate methods is that they are computationally intensive and it can be difficult to determine how the model arrived at a given result.

The ChemCam team currently uses the Partial Least Squares (PLS) method to derive major element compositions from target spectra [2,3]. PLS and most other multivariate regression methods use a "training set" of known spectra and corresponding compositions to predict the composition of an unknown target. To avoid overfitting the model to the training data, cross-validation is used to choose the number of components, and the estimated accuracy of the model is expressed as the root-mean-squared error (RMSE). All PLS-based quantitative ChemCam results available on the Planetary Data System (PDS) as Major Oxide Calculation (MOC) files list the estimated accuracy, along with the quartiles of the training set used for each element. Predictions that are near or outside the range of compositions in the training set are less reliable. The precision of ChemCam-derived compositions is better than the accuracy [10] (i.e., changes in measured composition are more reliable than absolute compositions).

Quantitative results available on the PDS are based on calibration that uses 66 geostandards [2,3]. Work is ongoing to develop an updated calibration based on an expanded database of 482 standards [3].

Image Data: For each LIBS observation, ChemCam also collects at least two RMI images: one before and one or more after LIBS, depending upon the number and geometry of analysis locations. These images provide context for the LIBS analyses and can be used to locate laser ablation pits and characterize the geology of the targets [11]. Mosaics of the RMI images (Fig. 2) associated with each LIBS observation, annotated with approximate LIBS analysis locations, are available on the ChemCam website [12] under the "results" tab. The RMI is also occasionally used to collect "standalone" images of targets independent of LIBS. Repeated RMI observations at different focus settings (Z-stacks) can be used to create focal merges and derive 3D information [11].

Data Access: To date, ChemCam data through Sol 804 are released on the PDS. These include active and passive spectral data (raw and processed), MOC files, RMI images (raw and processed, including standalone, Z-stack data, and mosaics), and LIBS spectra collected in the laboratory (used for calibration). ChemCam files on the PDS follow the naming convention in Fig. 3. ChemCam "quicklook" products are also available on the PDS, and the PDS provides the MSL Curiosity Analyst's Notebook, which provides a user-friendly way to access mission data [3,12].

The ChemCam team encourages scientists interested in working with the ChemCam data on the PDS to contact members of the team to assist in analyzing the data. A spreadsheet with contact information for the ChemCam science team is available at [3].

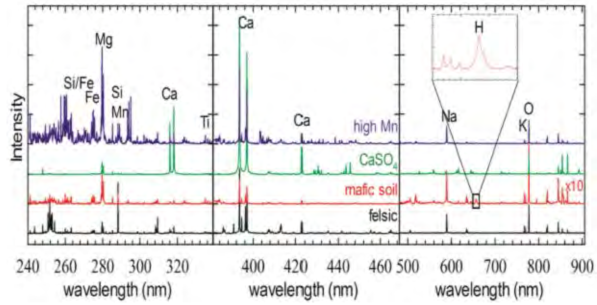

Fig. 1: Example processed ChemCam spectra of compositionally diverse targets on Mars.

Fig. 2: Example annotated post-LIBS mosaic of 3 RMI images. Mosaics of this type are available at [11].

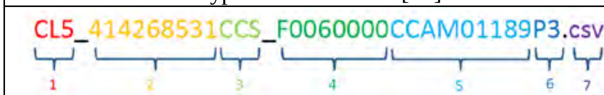

Fig. 3: ChemCam file naming convention. **1.** Data Type: CL5 = LIBS, CL9=Passive, CR0 = RMI, CL0 = Passive (averaged); **2.** Spacecraft clock; **3.** Processing level: EDR = raw, RDR = Level 1a, CCS = "Cleaned Calibrated Spectra" Level 1b, MOC = Level 2, PRC = processed RMI; **4.** Flight software version; **5.** Sequence ID; **6.** Processing version (always use the highest P# available); **7.** File type

References:[1] Knight, A.K., et al., 2000. Appl. Spectrosc. 54, 331–340. [2] Wiens, R.C., et al., 2013. Spectrochim. Acta B. 82, 1–27. [3] http://pds-geosciences.wustl.edu/workshops/ChemCam_Workshop_Mar15.htm [4] Gasnault, O. et al. (2015) 46th LPSC, #2789 [5] Anderson, et al. (2013, 44th LPSC, #2750. [6] Clegg, S.M., et al. 2009. Spectrochim. Acta B. 64, 79–88. [7] Ollila A.M. et al., (2012) Applied Optics 51, B130-B142. [8] Fabre et al. (2014) Spectrochim. Acta B, Vol. 99, pp. 34–51. [9] Ollila, et al. (2013) JGR, 119, 255-285. [10] Blaney et al. (2014), JGR, 119, 2109-2131. [11] Le Mouélic, S. (2015) Icarus, 249, 93–107. [12] http://results.msl-chemcam.com [13] http://an.rsl.wustl.edu

GENERATION OF A DATABASE OF LABORATORY LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) SPECTRA AND ASSOCIATED ANALYSIS SOFTWARE.
R.B. Anderson[1], S.M. Clegg[2], T. Graff[3],4, R.V. Morris[3], J. Laura[1], [1]USGS Astrogeology Science Center, Flagstaff, AZ (rbanderson@usgs.gov), [2]Los Alamos National Laboratory, [3]Johnson Space Center, [4]Jacobs Technology

Introduction: Laser-Induced Breakdown Spectroscopy (LIBS) is a technique that is relatively new in planetary science, capable of rapidly measuring the fine-scale elemental chemistry of targets from several meters away. The size and brightness of the plasma plume generated by the laser is highly dependent upon atmospheric pressure, as demonstrated by [1]. The atmospheric pressure on Mars is near-optimal for production of bright emission spectra. The ChemCam instrument on the Curiosity rover is the first planetary LIBS instrument, and SuperCam on Mars 2020 will have similar LIBS capabilities. LIBS can also be used effectively on other planetary bodies such as the Moon [2,3], Venus [4,5], asteroids [6], and Titan [7].

This abstract describes recently-funded plans to generate a database of LIBS spectra of planetary analog materials and develop freely-available software to enable the planetary science community to analyze LIBS data.

Spectral Database: The proposed database of spectra will be collected using the LIBS system in the Spectroscopy and Magnetics Laboratory at Johnson Space Center (JSC), and using the ChemCam engineering model at Los Alamos National Laboratory (LANL). The JSC system uses a Nd:YAG 1,064 nm laser with variable energy per pulse and a HR2500+ Ocean Optics spectrometer with a resolution of 0.035 nm and a spectral range of 200-1,100 nm. The LANL system is nearly identical to the ChemCam flight model. The ChemCam instrument uses a Nd:KGW laser to produce 5 ns pulses of 1067 nm light. The laser can be focused up to a distance of ~7 m. The beam energy is typically 14 mJ per pulse, though this can be decreased by adjusting the current to the amplifier diode stack. The three ChemCam spectrometers each have 2048 spectral channels, for a total of 6144 channels in a full ChemCam spectrum. The wavelength ranges are 240.1-342.2 nm, 382.1-469.3 nm, and 474.0-906.5 nm and the spectral resolutions are 0.15 nm, 0.20 nm, and 0.61 nm, respectively [8].

The samples in the spectral database will include duplicates of the eight geologically relevant ChemCam calibration targets, as well as 31 powdered geostandards that have also been analyzed by ChemCam. An additional seventeen samples are synthetic glass beads that have been generated with volatile-free compositions that match targets observed by MER APXS. Additional samples in the database will be drawn from the JSC planetary analog collection, many of which have been analyzed by numerous other planetary science instruments (e.g., Mossbauer, VNIR reflectance, Thermal Emission, Pancam, Mastcam, etc.).

All analyses on both instruments will be conducted under a Mars-composition (2.7% N_2, 1.6% Ar, 95.7% CO_2) atmosphere at martian pressure (~5 Torr). All samples will be analyzed at three or more different laser energies to provide a data set that can be used to investigate the effect of laser energy density on the resulting LIBS spectra. Spectra will be recorded with appropriate metadata describing the sample (including sample ID, the rock or mineral name, the sample collection locality or vendor, and a high-resolution photograph of the sample) and the experimental conditions (chamber pressure, gas composition, laser wavelength, laser power, laser-to-sample distance, etc.).

Analysis Software: To accompany the spectral database, we will be developing a LIBS data analysis tool in Python for use by the planetary science community. This tool will be free and open-source, and will include the following data processing and analysis capabilities:

Preprocessing: Common pre-processing steps for LIBS spectra include mean-centering (a common first step for multivariate methods), normalization to reduce the effect of random fluctuations in beam quality, and masking of some regions of the spectrum to remove instrument artifacts or emission lines that are not of interest. Continuum removal is also desirable, particularly for systems such as ChemCam that are not time-gated and therefore collect signal from the entire evolution of the spark [9]. The software will follow the ChemCam continuum removal procedure, using a stationary wavelet transform and spline fit to identify minima in the spectrum and fit a continuum to them [9].

Qualitative Methods: Principal Component Analysis (PCA) is a commonly used method for reducing the dimensionality of a data set by decomposing it into multiple orthogonal components [10]. Independent Components Analysis (ICA) is a related method but instead of enforcing orthogonality, the algorithm seeks to minimize the statistical dependence between components [11]. PCA can more-efficiently describe the data set, while ICA has the advantage that its loadings tend to correspond to a single element [12], so ICA scores serve as a qualitative measurement of the strength of that element's emission lines in the spectrum.

ICA or PCA scores are often used as input to clustering and classification algorithms. The software developed in this work will include k-means clustering and hierarchical clustering. Hierarchical clustering applied to ChemCam data has been shown to be an effective way of identifying major compositional trends [13].

Classification differs from clustering in that it begins with pre-defined classes and assigns new spectra to the class which they match most closely. We will implement Soft Independent Modeling of Class Analogy (SIMCA), a common classification method in chemometrics [14,15,16], that has been shown to be effective for classifying LIBS spectra [17, 18].

Quantitative Methods: In addition to qualitative analysis of LIBS data, quantitative analysis is also possible using multivariate methods. The developed software will focus on multivariate analysis methods and will include all of the methods discussed below, though "univariate" methods based on the strength of an individual emission line have been shown to be effective in some cases, particularly for minor and trace species [19].

The ChemCam team uses the multivariate method Partial Least Squares (PLS) [9] for quantitative results. PLS is related to PCA in that it creates a model of a data set by re-projecting it onto a small number of components, but differs in that PLS incorporates both independent variables (spectra) and dependent variables (chemical compositions).

Support Vector Regression (SVR) is an alternative to PLS [20]. This technique seeks to identify data points in the data set whose position defines a hyperplane of regression for the data. SVR is capable of modeling non-linear relationships by using kernels that map the data into spaces where hyperplanes are more easily calculated. SVR has been shown to be more accurate than PLS in some applications [21].

Artificial neural networks (ANNs) are another class of method that has been used with some success to analyze LIBS data, yielding results comparable to or better than PLS [22, 23]. ANNs have several advantages including a high tolerance for noise and the ability to model non-linear relationships [24]. One of the challenges of using neural networks is optimizing the number of neurons in the network. This optimization can be done by implementing genetic algorithms to find the best network structure [22, 25]. Genetic algorithms can also be used to conduct feature selection, identifying portions of the spectrum that have the strongest influence over the performance of a model [22,26].

Calibration Transfer: Calibration transfer methods can be used to correct for differences between instruments [27] so that a calibration model derived for one instrument (e.g., a laboratory LIBS instrument) can be used with data from another instrument or collected under different conditions (e.g., ChemCam on Mars). These methods require the same targets to be analyzed by both instruments so that corrections can be determined. PLS has been demonstrated as an effective calibration transfer method for LIBS data [28]. Another widely used calibration transfer algorithm is called piecewise direct standardization (PDS) [27]. By implementing calibration transfer, the spectral library proposed here can be compared to LIBS spectra collected on other instruments, both from other laboratories and from ChemCam and SuperCam on Mars, as long as a set of common samples such as the ChemCam calibration targets have been analyzed.

Conclusion: The goal of this work is to make a database of LIBS spectra of planetary analogs, and the associated software required to analyze those spectra, readily available for the planetary science community. The software will also be useful for analysis of other spectral data sets. This work is in its early stages, and we welcome feedback from the community regarding how to make these products as useful as possible.

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STATUS OF THE IAU WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS AND ITS UPCOMING REPORT.
Brent A. Archinal, U. S. Geological Survey, Astrogeology Science Center, (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA barchinal@usgs.gov).

Overview: Approximately every 3 years since 1979, the Working Group on Cartographic Coordinates and Rotational Elements (hereafter the "WG") of the International Astronomical Union (IAU) has issued a report recommending coordinate systems and related parameters (e.g. body orientation and shape) to be used for making cartographic products (maps) of Solar System bodies. These recommendations are based on community consensus as interpreted by a diverse international group of mapping experts, and are intended to facilitate the use and comparison of multiple datasets by promoting the use of a standardized set of mapping parameters. This abstract is intended to draw attention to the WG's efforts, our previous reports (e.g. [1]), and our 2015 report that is now being written (i.e., there will be no "2012" report). The WG encourages input and is available to assist users, instrument teams, and missions on cartographic issues. See our website [2] for additional information.

Operation of WG: The WG currently consists of 19 volunteer members from 6 countries: C. Acton, M. A'Hearn, B. Archinal (Chair), A. Conrad, G. Consolmagno, T. Duxbury, D. Hestroffer, J. Hilton, L. Jorda, R. Kirk, S. Klioner, D. McCarthy, K. Meech, J. Oberst, J. Ping, K. Seidelmann, D. Tholen, P. Thomas, and I. Williams, representing China, France, Germany, UK, USA, and the Vatican City State. Following nominations, volunteers are elected at the IAU General Assembly (GA) to serve for a three year term, which may be renewed. The WG looks at new determinations of coordinate systems (e.g., body sizes and orientations) that preferably have been published in refereed papers, and makes recommendations as to which to use, based where possible on consensus decisions. As a volunteer organization, the WG has no resources to verify results or conduct its own research so it relies only on published results and community input. For that reason it is sometimes not possible to recommend one set of results over another. The WG cannot verify or "bless" any particular results by independent research, and has no "enforcement" powers, but tries, in reflecting the long term planetary community consensus, to make persuasive recommendations.

The WG does not deal with issues related to mapping product formats. Such issues have largely been left to individual map developers, archiving organizations such as the NASA Planetary Data System (PDS), the International Planetary Data Alliance, or the NASA Mars Geodesy and Cartography and Lunar Geodesy and Cartography Working Groups (MCGWG[3], LGCWG[4]) and individual missions. Input from such organizations has been welcomed by the WG and the frequency of interaction highlights the strong need for such organizations at mission, space agency, and international levels. The WG looks forward to collaborating with the new NASA Cartography Research Assessment Group (CRAG) [5].

In discussions at the IAU GA in August 2012 there was agreement [6] to remind authors, journal editors, instrument teams, missions, and space agencies that a substantial number of IAU recommendations exist that have been developed over many decades of input by IAU members, national space agencies, and other institutions. Care should be taken to follow such recommendations or to present well-reasoned arguments why they should be changed. The IAU and its Working Groups stand ready to help such groups understand and follow IAU recommendations.

Defining Longitude: One continuing issue is the question of how the definition of longitude should be updated on Solar System bodies. The WG addressed this issue in its first report [7] and reiterates in the recent report [1] that once an observable reference feature at a defined longitude is chosen, the alignment of the longitude system should not change. Given that our definition of longitude is primarily for mapping surface features, it is more logically tied to data related to the surface of the body (e.g., direct imaging or altimetry) than to dynamical data (e.g., the principal axes of inertia for resonantly or synchronously rotating bodies such as Mercury [8], the Moon, or Jovian or Saturnian satellites). Once such a feature has been adopted, changing the longitude system alignment should be avoided. Note that this recommendation does not preclude the use of smaller or more precisely determined features, multiple features, or even human artifacts to define longitude, as long as the original alignment is maintained to the level of precision at which the feature can be located in new data. An example is the redefinition of the origin for longitude for Mars from the large feature then known as Sinus Meridiani to the small crater Airy-0 [9]. Some shift in longitude of previously identified features may occur whenever new data are available and processed, but this is minimized at least in the vicinity of the defining feature.

Coordinate System for (4) Vesta: In August 2011, the NASA/DLR/ASI Dawn mission proposed using a longitude system with a large (~155°) rotation from the previous [10] system. Many reasons were expressed for this new system, but the WG replied in both September 2011, and March 2012, after careful and extensive consideration, that the arguments were not compelling enough to ignore previous usage by the planetary community and the WG's previous recommendations. Unfortunately, the mission began publishing results using only their rotated system [e.g., 11]. The change in system has resulted in substantial confusion. Fortunately, the NASA PDS requires that archived data products follow various standards, including those of the IAU. The mission therefore proposed a new system, which the PDS did accept as agreeing with IAU recommendations. This system is as described in the archive [12] (with W_0=285.39º). The WG was asked by the mission for concurrence on the suitability of this latest system, and did so in November 2012. The WG also recommended that to avoid further confusion, maps and scientific publications should henceforth use the same primary system as the data archives. The Dawn mission has published data to the PDS using the new compliant system. The WG also explicitly recommended this system for general use for Vesta [13].

General Changes Under Discussion: Following extensive discussion, the WG has developed a working list of changes and updates for the next report. Details of these changes are still being addressed, but this and the following section provide an overview. *First*, based on the experience with Vesta, the WG will reword and clarify its recommendations regarding updating longitude. *Second*, mission and community input indicates a need for the WG to differentiate between body shapes and sizes for image projection and scientific modeling versus a reference surface for elevation and map scale. In particular, long-accepted values for the latter will be documented for the Moon, Mars, and Titan. *Finally*, the WG will likely become a "Functional group" under the new IAU structure, where such groups would have the "main responsibility of [providing] state-of-the-art deliverables: standards, references; tools for education, related software (VO), etc., with an official IAU stamp, for universal use" [14].

Changes for Specific Bodies Under Discussion: Due to past confusion in their use, formulae for the Earth's orientation (which had been given for comparison purposes only) will be removed. For the Moon, the availability of a new JPL lunar ephemeris (DE430) will be pointed out, but its adoption may not be recommended given that another JPL ephemeris is likely to be released in early 2016 (W. Folkner, personal comm.). The availability of the current INPOP ephemeris [15] will also be described. The recommendation of a new orientation model for Mars [16] by the MGCWG will be followed [17]. Cassini results will be considered regarding updates for the Saturnian satellites. Neptune's rotation model will be updated based on results from Karkoschka [18]. New or updated values will likely be adopted for (2) Pallas, (21) Lutetia, (52) Europa, and (511) Davida. Correct values will be used for the size of (25143) Itokawa. Recent determinations of variable rotation rates for 9P/Tempel 1 [19] and 103P/Hartley 2 [20] will likely be recommended.

Outlook for Later Reports: Specific changes for the 2018 and later reports will depend largely on what new results are published. We can speculate regarding updates or new values in several areas including a) using human artifacts to define longitude, e.g. on the Moon with the lunar laser ranging retroreflectors (LRRR) and on Mars with the Viking 1 or planned InSight landers; b) further improvements in the lunar ephemeris; c) updates for the orientation of Jupiter and Saturn; and d) updates due to new results from ongoing and new missions (e.g. missions to Mercury, Saturnian satellites, Pluto and Charon, (1) Ceres) and Earth-based observations (various asteroids). Consultation is needed within the IAU as to whether the WG should make any recommendations regarding extrasolar "planets." The WG has been looking into establishing links to related organizations, such as the International Association of Geodesy and the International Society for Photogrammetry and Remote Sensing. The WG will continue to provide assistance on coordinate system and mapping issues to the planetary community (e.g., missions, product developers, the new NASA CRAG, etc.) on a best-effort basis.

Request for Input: The WG desires continued input from the planetary community, especially regarding the systems for specific bodies, the operation of the WG, and the need for and/or usefulness of the WG's efforts. The lead author of this abstract should be considered the primary point of contact.

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THE NASA PLANETARY DATA SYSTEM: PAST, PRESENT, AND FUTURE. R. E. Arvidson, Earth and Planetary Sciences, McDonnell Center for the Space Sciences, Washington University in Saint Louis, Saint Louis, MO, 63130, arvidson@wunder.wustl.edu

Introduction: Archiving and distributing data sets from NASA's planetary missions has evolved from depositing data in central repositories, without systematic reviews, to a structured process of planning, reviewing, validating, and distributing archives containing raw and derived data sets and extensive documentation. The need for and history of development of the Planetary Data System is described, followed by current status and prospects for the future. Personal perspectives are used, based on experience working on missions and archiving starting from the Mars Viking Lander Missions in 1976 through current missions.

History: Archiving in the 1960s and 1970s focused on depositing data sets and documentation in the National Space Science Data Center (http://nssdc.gsfc.nasa.gov/) and was typically done without peer review of the nature, content, or thoroughness of the archives. The development of the Regional Planetary Image Facilities (http://www.lpi.usra.edu/library/RPIF/index.shtml) enhanced the ability of researchers to access hardcopies of images acquired by planetary missions, along with derived data sets such as topographic and geologic maps. The RPIFs were sited at geographically dispersed locations where planetary scientists were present to direct the RPIFs and to provide expert advice to visitors. The RPIFs continue to expand their holdings and still focus on image collections, expert advice, and local outreach and education.

The National Research Council's Space Science Board initiated a Committee on Computation and Data Management (CODMAC) to provide an analysis of the state of archiving and recommendations for improvement. Three reports were generated in the 1980s before CODMAC was decommissioned [1,2]. A key finding, based on extensive analysis of archive facilities and the extent to which they were used by science communities for data mining and discoveries, was that the most useful archives were managed by scientists who used the data and understood the details of the holdings. This led to the recommendation that distributed archives, sited at institutions with significant science presence, and run by scientists, would provide archives that would maximize the ability to make new discoveries.

The CODMAC recommendations were critical to the development of the Pilot Planetary Data System (PPDS) in which concepts associated with development and management of distributed data centers were tested. Proposals were then solicited and peer-reviewed, and a set of discipline-oriented data nodes were selected in 1989 to form the core of the PDS. These included Geosciences, Atmospheres, Small Bodies (asteroids and comets), Planetary Plasma Interactions, Rings, Imaging (focused on archiving large raw and derived imaging data sets and the ability to generated derived data), Navigation and Ancillary Information Facility (NAIF), and a Central Node for management.

Current Status: The current version of the PDS has the same discipline nodes, the Imaging and NAIF Nodes, and the addition of an Engineering Node to help facilitate developments that transcend individual nodes. Structured approaches have been developed and followed for working with mission instrument teams and other suppliers of candidate archives. This approach includes initial planning of archive contents and delivery schedules, generation and peer review of contributions, ingestion into the relevant PDS Node, making the archives available via web-based interfaces, and deposition of archives with the NSSDC for long-term back-up. As an example, the Geosciences Node supports archives totaling ~165 terabytes of data for Mercury, Venus, Earth's Moon, and Mars, with 346 data sets and ~4.3 terabytes of user downloads per month. User interfaces include Orbital Data Explorers (http://ode.rsl.wustl.edu/), and for landed missions, Analyst Notebooks (http://an.rsl.wustl.edu/). Both interfaces retrieve data from other PDS Nodes, if needed, packaging on the fly archives for user downloading. On an international level PDS standards have been adopted by European, Russian, Indian, Chinese, and Japanese missions when generating archives.

Prospects for the Future: The PDS is currently transitioning from the existing PDS-3 archive structures and formats to a more modern, streamlined PDS-4 approach. PDS-4 features more strictly defined data formats, an updated information model based on international standards, and use of XML to facilitate data and metadata access by multiple software tools. New mission contributions will be archived using these streamlined approaches. In addition, a renewed emphasis on recovery of old data sets and generation of new derived products by the research community (e.g., PDART Program) is leading to a rapid increase in archive contributions that will be of direct benefit to the community. A major task for archivists in general will be to integrate across various planetary archives and data holdings (e.g., extraterrestrial sample holdings at the NASA Johnson Space Center and the Planetary Cartography and Geodesy Program at the USGS, Flagstaff) to provide a more seamless way for users to search, access, and utilize planetary archives. Finally, although management limitations rather than technology limitations have always been considered the greatest impediments to better archives, the PDS must continue to be aware of and take advantage of new technologies to make archiving and distributing more efficient and informative. A recent example is the announcement by Microsoft of Hololens technology that will allow three dimensional visualization of planetary archives in an office environment.

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FINDING STEREO PAIRS WITH THE PDS PLANETARY IMAGE LOCATOR TOOL (PILOT)

M. S. Bailen, K. E. Herkenhoff, E. A. Howington-Kraus, K. J. Becker. U. S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ, 86001 (mbailen@usgs.gov).

Introduction: Creating a topographic model is often the first step in performing research such as slope and roughness analysis; landing site determination; wind, water, landslide and lava flow modelling; orthorectification for cartographic products, anaglyph creation, simulated 3D flyovers, and more [1]. Researchers in pursuit of topographic models have developed one-shot stereo-matching tools for specific targets, regions, instruments, and data sets; but as of yet, members of the planetary scientific community have not devised a flexible and comprehensive stereo-matching tool. The Planetary Image Locator Tool (PILOT) [2] aims to fulfill this need with its new stereo-matching feature. PILOT is equipped with a web-accessible easy-to-use interface to locate and evaluate stereo pairs, quickly performing evaluations that require instrument-dependent specifications for culling the data. The tool has the ability to search current data from mission archives, easily adjust constraints (including resolution, incidence angle, emission angle, intersect area, convergence angle and other photometric keywords), and allow further culling of the data through online visual assessment of imagery and geometry.

Background: PILOT is a web-based search interface (http://pilot.wr.usgs.gov) supported by the USGS Astrogeology Science Center and the NASA/USGS Planetary Data System (PDS) Imaging Node. PILOT provides access to NASA's largest archive of spacecraft imagery, the PDS Imaging Node. Searches performed through PILOT are simplified by a planetary mapping interface and an advanced constraint panel to allow easy and incisive culling of the archive data. Searches are further enhanced by sourcing the geospatial information, thumbnail and browse images, metadata and photometric keywords stored in the Unified Planetary Coordinates (UPC) database [3].

Usage: PILOT's stereo-matching tool was developed to locate stereo pairs over targeted regions, not entire planetary bodies. To maintain the speed and responsiveness of the tool, accessing the tool is restricted to successful PILOT searches with less than 250 images. If an area of interest contains greater than 250 images, further restrictions can be set by defining a latitude/longitude bounding box (map tab) or setting limits for photometric values (advanced tab). To activate the stereo matcher, the user must select the tab marked *Stereo* at the top of the display. Once selected PILOT computes all possible spatial intersects for the search results. An interactive panel (Figure 1, lower half) slides open and displays the intersects along with options to select and map specific pairs. Information such as convergence angle, intersection area and the variance between photometric keywords (e.g. solar azimuth, emission angle, etc..) are provided through the interface.

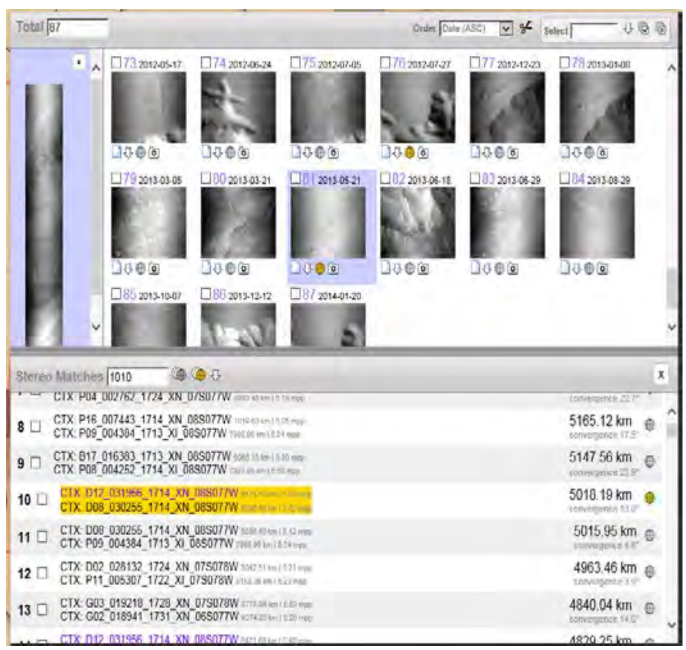

Figure 1: Example of the stereo matching interface in PILOT. The lower panel slides open to display possible stereo matches.

On-The-Fly Culling: Upon computing the spatial intersects, PILOT allows for on-the-fly culling of the result set through sliders and input boxes on the stereo tab (Figure 2). The culling occurs in real time (computed by the browser), thus providing an immediate and interactive experience when adjusting stereo-specific parameters (e.g. resolution, incidence angle, emission angle, intersect area, base-height ratio, convergence angle and other photometric keywords). The flexibility provided by the stereo tab invites users who are familiar with specific instruments, targets, and regions on a planetary surface to quickly perform the necessary adjustments for their particular area of interest.

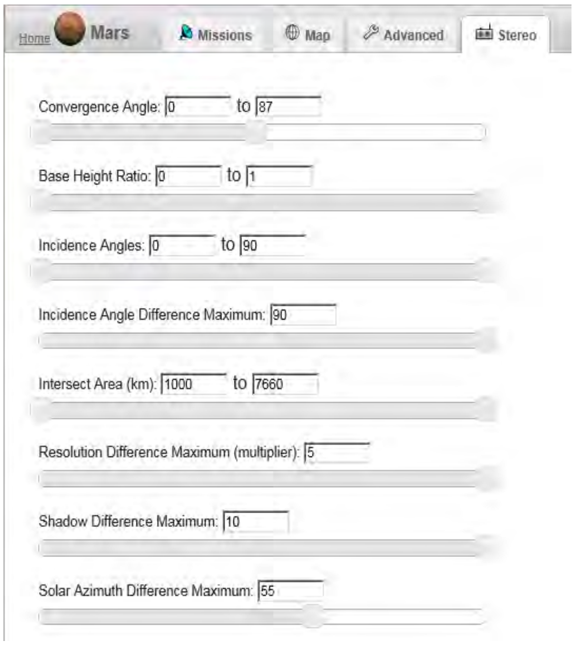

Figure 2: Stereo tab with sliders and input boxes to adjust stereo-specific parameters.

Stereo Coverage Mapping: Once the stereo matches have been selected and culled, PILOT's map tab can be used to examine the stereo coverage within the area of interest (Figure 3). The map tab is interactive, allowing selection, removal and further examination of the intersections. In addition, the individual footprints that make up stereo pairs can be mapped on top of an intersection to verify the coverage area.

Credit: The development of PILOT's stereo matching tool was supported by the MRO HiRISE Project and the USGS Astrogeology Science Center.

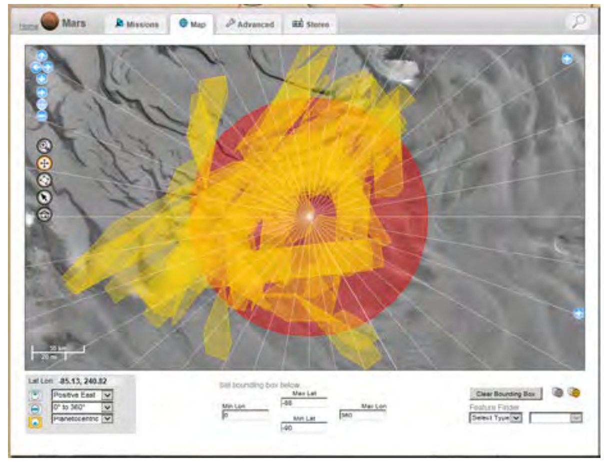

Figure 3: Example of a stereo coverage map for MRO CTX on the south pole of Mars.

Technical Details: By sourcing the UPC [3], the PILOT stereo-matching tool takes advantage of corrected geospatial and photometric details as generated by the USGS Astrogeology ISIS system [4], details that are typically not available through labels provided by the PDS. While some stereo-matching tools locate intersects by finding center points contained in mutual pairs, PILOT is able to perform more exact intersect searches by referencing the entire footprint geometry of images in a geospatially aware database, PostgreSQL/PostGIS [5]. Computing photometric keywords (e.g. incidence angle, emission angle, solar azimuth, etc.) and values derived from these keywords (convergence angle, base-height ratio), rely on maximum, minimum, and center values for these keywords. For many images, these values contain significant variance over the span of an image and a margin of error should be expected. To help determine the margin of error, a range of convergence angles is computed and displayed in the stereo panel. Intersect areas are computed using a geodesic formula with IAU accepted radii. Suggested stereo criteria are a result of cooperative mapping projects completed at the USGS Astrogeology Science Center. [6]

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ISIS WORKSHOPS USING VIRTUALIZATION. Kris J. Becker and Tammy L. Becker, U. S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ, 86001 (kbecker@usgs.gov).

Introduction: The Integrated Software for Imagers and Spectrometers (ISIS) [1] version 3 system provides image processing and cartographic mapping capabilities for many NASA missions, instrument team's ground data processing (GDP) systems [2], and the scientific user community [3] at-large. The USGS Astrogeology Science Center (ASC) has provided web-based and hands-on ISIS workshops for instrument mission teams and science users. The diversity of the workshop topics, number of participants and computing resources have presented challenges in providing efficient and effective workshops. Recently, we have developed workshops using machine virtualization technology, or virtual machines (VM), with VirtualBox [4]. This has resolved many technical issues encountered in past hands-on workshops as well as supplied participants an ISIS platform which can be further customized for their specific needs beyond the scope of the workshop materials presented.

Discussion: ISIS is comprised of over 300 applications and provides support for more than 55 NASA and European imaging devices [2]. It is a complex system with a steep learning curve. However, once mastered, ISIS provides a comprehensive image processing system that can produce high quality cartographic products created from datasets acquired by different instruments.

History: Hands-on workshops have been conducted for spacecraft mission instrument teams since ISIS2 was used for Clementine and Galileo missions followed by ISIS3 for the Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) team (one of the first adopters of ISIS3) and more recently teams such as MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) Dual Imaging System (MDIS) and Lunar Reconnaissance Orbiter Camera (LROC). There have been a number of workshops for the general community provided as well.

Requirements and Logistics: A successful hands-on workshop requires a stable, reliable and efficient computing environment. Focus is on interactive learning of ISIS and the cartographic concepts and techniques through prepared lessons. It is imperative that participants are not interrupted with network bottlenecks or inadequate computing resources. This can only be achieved by overcoming the challenges created by the number of participants, requirements for disk space, computing power, network connectivity, graphics support and limited support for OS configurations.

Disk Space: ISIS system installation size requirements can be reduced by selecting and installing supporting data (i.e., SPICE kernels, calibration files and other ancillary data) for only those missions needed by users (or a workshop lesson).

Copies of all workshop materials and image datasets made available to each participant may require large amounts of disk space. Running ISIS image processing application steps provided in each lesson increases storage requirements as intermediate output products are created.

OS Platform: ISIS is currently supported on several popular Linux distributions including Scientific Linux and Fedora, both Redhat based systems, Debian and Ubuntu. Also supported are MacOSX (10.6 and above) platforms. The Scientific Linux operating system (OS) is used to host ISIS workshops for no particular reason other than it is Linux-based and arguably the more popular and widely used distribution. Some of the ISIS lessons are graphics intensive in nature and require an X client for each participant.

CPU: ISIS applications executed in the lessons have moderate CPU requirements. Computer systems used by more than one participant may easily be overwhelmed when lesson scripts are run simultaneously on the same machine. Modern laptops provide a suitable platform for most workshops provided adequate disk resources are available.

Results: We have continuously modified our hands-on computing environment to meet workshop objectives while keeping pace with technology and ISIS system evolution. Additional problems have been discovered as we increasingly scale the workshops, both in number of participants and requested advanced topics covered in the hands-on lessons.

Lessons Learned: Early workshops required users to provide the hardware and an ISIS system installation to use for the hands on lessons. ASC instructors provided workshop materials and the data needed for the hands-on lessons that were presented. It quickly became apparent this did not provide a consistent, stable environment and a lot of time was spent getting ISIS installed properly and/or working through problems encountered while executing lessons in the student's environment.

Workshops have been conducted on Linux computers configured with full ISIS installations. This configuration would accommodate several participants per machine, require many computers to be configured with ISIS and workshop materials, and but resulted in competition for compute resources.

Some successful workshops were conducted using three Mac minis with Fedora Linux installations, full ISIS configurations and wireless routers to provide access to users. Users were assigned unique student logins and used wireless access points to connect to an assigned Mac mini. Problems arose with this approach as the minis could not handle more than several users per system and the wireless channels quickly became overloaded when graphical processing dominated network traffic. Some problems were alleviated with direct hardwire connections to the minis, but CPU contention still remained.

ISIS Virtualization: Problems of scaling ISIS within an educational setting exist not only because of student numbers, but also because of hardware and OS limitations and connectivity to resources. To address these issues, we have designed a virtualization solution using a VirtualBox VM.

A main objective of any solution is to address known problems while at the same time keep from introducing new problems or limitations. VMs have shown to provide one solution with minimal impact on the user experience.

VM Specifications: The ISIS workshop VM was initially create using Vagrant [7]. Vagrant is designed to use VirtualBox as its virtualization provisioning system (mainly because VirtualBox is free). This approach provides the initial VM configuration with a very minimal Linux installation footprint. We chose to install Scientific Linux 6.5 using a preconfigured Vagrant *box*, an existing Vagrantfile developed using a specific OS installation procedure. For our objectives, we chose a small box that did not install unnecessary software. Another goal is to keep the VM size as small as possible to ease installation and minimize workshop startup time.

Once the initial VM is created, it is copied into the VirtualBox default VM directory and Vagrant is abandoned. The reason for this is to minimize user requirements by limiting software dependencies for use of the VM.

Three basic users are provided in the VM, each with a specific purpose in mind:

- ***student*** – This is the primary user account that will be used for most all normal operations. The home directory of this user has a directory named *IsisWorkshop* that contains all the files used in the workshop
- ***isis3mgr*** – The ISIS3 manager account. Management of ISIS is separated from the student account so that it is not accidently corrupted or modified by any users.
- ***vagrant*** – The account under which all Linux administration and activities that require root permissions should be used.

To simplify use, passwords for all accounts are the same as the account name (i.e., password for the **student** account is "student").

ISIS Configuration: The goal for the ISIS installation is to provide a complete processing environment while keeping the install size to a minimum. Image data used by the hands-on lesson scripts identify only the required ancillary ISIS files. They are placed into a data directory structure that emulates a normal ISIS data installation. This is the most challenging part and customized aspect of creating the VM environment. Attempts are made to keep ISIS installations current to support coordinated ISIS release cycles. A simple startup script, used by developers and users at the ASC, is installed in the VM to maintain consistency.

All VM configurations include installation of FWTools, including GDAL, to support ease of importing and exporting data to and from ISIS.

User VM Installation: The components of a complete VM workshop package is 1) the ISIS VM including all lessons, 2) documentation and presentations of the workshop materials including a VM installation guide and 3) tar files containing ISIS applications and custom ancillary data configurations. The tar files are provided for users who have a compliant ISIS installation from which the lessons can be ran.

All these files are configured to fit on a USB 3.0 drive formatted with an NTFS file system. NTFS was chosen because of its (read-only) compatibility with most VM host OSes. The ISIS workshop VMs are typically around 11 gigabytes in size. The installs (transfers) complete in a few minutes to the students computer system. Students are required to have VirtualBox installed on their computers to expedite the VM installation process and to confirm support for their OS. Some laptops require virtualization to be "turned on" in the BIOS as it may not enabled by default.

Instructions are provided to guide the user through installation of the VM in VirtualBox and optimizing its performance through host tools provide by VirtualBox for supported systems. The whole installation process takes about 15 minutes.

Conclusions: ISIS workshop scaling problems have been reduced by use of virtualization techniques using a VirtualBox VM running the Scientific Linux guest operating systems and a custom ISIS installation. Users provide the hardware and sufficient disk space to run the hands-on lessons. Once the workshop is complete, users now have an ISIS system which is capable of installing all of ISIS for additional use – something previous workshops did not provide. All of the scaling issues identified in previous workshop computing environment configurations are reduced or eliminated entirely. This ISIS configuration is available on all systems that support VirtualBox including Windows and MacOSX systems. We are also investigating ISIS development options using virtualization technology.

References: [1] Anderson J. A. et al. (2004), *LPSC* abstract #2039. [2] Becker K. J. et al. (2013), *LPSC* abstract #2829. [3] Kestay L. et al. (2014), *LPSC* abstract #1686. [4] https://www.virtualbox.org/. [5] Torson J. M. and Becker K. J. (1997), LPSC abstract #1219. [6] Becker K. J. et al (2007) LPSC abstract #1779. [7] https://www.vagrantup.com/.

USING OPEN INNOVATION TO SOLVE NASA PLANETARY DATA CHALLENGES. L. Buquo[1], S. Rader[1], C. Woolverton[1], A. Wolf[1], C. Galica[2], K. Becker[2], M. Ching[2] , [1]NASA Center of Excellence for Collaborative Innovation (NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX, 77058, Lynn.Buquo-1@nasa.gov) for first author, [2]Stellar Sollutions, Inc (NASA Heaquarters, 300 E St SW, Washington, D.C., Carol.A.Galica@nasa.gov)

Introduction: In 2011, the Administration launched the Center of Excellence for Collaborative Innovation (COECI), a NASA-led, government-wide center of excellence to provide agencies guidance on all aspects of implementing prize competitions: from effective problem definition, to the design of incentives that attract solvers, to evaluation of submitted solutions. CoECI helps NASA generate ideas and solve important problems by using challenges, to increase creative capacity and reach by tapping into diverse talent from around the world. As a pioneer and active user of open innovation methods and tools, the NASA CoECI provides organizations with a cost-effective and complementary means of extending their innovation boundaries. CoECI will highlight four successful challenges related to planetary data that were conducted in partnership with the planetary data community. Through COECI, NASA helps other Federal agencies follow in its footsteps. For select agency pilots conducted through interagency agreements or through informal support, COECI leverages existing NASA open innovation infrastructure to provide a full suite of services, allowing agencies to rapidly experiment with these new methods before standing up their own capabilities. During 2014, COECI helped numerous agencies implement challenges, including CMS, the Office of Personnel Management (OPM), USAID, DOE, and EPA.

Lunar Mapping and Modelling Portal (LMMP) Challenge: The LMMP challenge focused on technology development. It required development of a Mosaicking Service tool to perform image processing that transforms the raw images taken by the Lunar Reconnaissance Orbiter (LRO) to geo-referenced and mosaicked images that can be displayed on the Lunar Mapping and Modelling website. Solvers were required to take parameters describing a set of images, do the image fetching and conversion, and perform mosaicking. They utilized a modified version of the Planetary Data System (PDS) Application Programming Interface (API) to handle the image fetching from Orbital Data Explorer (ODE), and will store the output files somewhere that the caller (Tiling service) can retrieve it from. The solution should reduce the time required to create high resolution geo-referenced mosaics of images taken from the LRO.

Planetary Data System (PDS) Cassini Rings Challenge: The Cassini Rings Challenge was launched to advance scientific research. It leveraged the PDS API, as well as the rich archive of Cassini data at the PDS-Rings Node hosted by SETI, and the Appirio-Topcoder community of competitors afforded by the NTL, in an effort to develop an algorithm that can identify possible anomalies in Saturn ring patterns. The algorithm employs machine learning techniques to automatically "learn" image annotation from a set of images previously annotated by researchers, and will apply this learning to accurately annotating a new set of unprocessed images. The completed algorithm may also be applied to previously annotated images, to identify other possible anomalies, and will be able to learn from new annotations as they are provided. To accomplish these goals, the algorithm will leverage the PDS API, Cassini image and meta data, and will be able to parse sequential image sets to detect cross-image anomalies.

Asteroid Tracker Challenge: The Asteroid Data Challenge created an algorithm that can continuously determine the optimum selection of subsets of antennas within an array for a given track observation. This is a complex analysis and goes directly to development of the concept of operations and cost of operations (in terms of maintenance and total capacity required). The requirements for this algorithm were as follows: be able to model phased array antenna beams using a predetermined set of dish and beam properties, take, as input, trajectories of a number of NEO and for each, be able to provide the optimal selection of sub-arrays to track the object for its entire visible path (or, if defined, a minimum time period of observation that gives sufficient scientific observation value); and be able to read properties from configuration files – i.e. dish properties, array configuration, trajectory data, etc.

Asteroid Data Hunter: The Asteroid Data Hunter Challenge provided a new algorithms to promote science. Scientists find asteroids by taking images of the same place in the sky and find the star-like objects that move. With many telescopes scanning the sky during the time around the new moon, the large data volumes prevent individual inspection of every image. Traditionally, the identification of asteroids and other moving bodies in the Solar System has been achieved by acquiring images over several epochs and detecting changes between frames. This general approach has been used since before the discovery of Pluto and continues to this day. With the vast amount of data available now flowing from modern instruments, there is no good way for professional astronomers to verify every detection. In particular, looking in the future as large surveys grow ever larger, the ability to autonomously and rapidly check the images and determine which objects are suitable for follow up will be crucial. Current analysis implies that at best the CSS data pipeline is 80 – 90% accurate and there are (based on CSS discovery numbers) several thousand additional objects that could be recovered per year. Starting from a fresh position allows specific optimizations of data analysis, which would be useful as a general moving object pipeline system for other observatories as well. The Asteroid Data Hunter Challenge developed an original algorithm that allows the discovery of new asteroids by analyzing images, created an app that is so easy that citizen scientists, hobbyist astronomers and even professional organizations/institutions will want to download it and ensured that the new algorithm can help to increase the amount of asteroids being detected.

Developing a multi-mission geographic information system (MMGIS) for in-situ planetary missions.

F. J. Calef III[1], H. E. Gengl[1], T. J. Parker[1], and R. G. Deen[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Fred.Calef@jpl.nasa.gov, Hallie.E.Gengl@jpl.nasa.gov, Timothy.J.Parker@jpl.nasa.gov, Bob.Deen@jpl.nasa.gov.

Introduction: The complexity, variety, and resolution of datasets for in-situ missions has grown. Missions, specifically at Mars, have transitioned from single-point landed missions like Viking to observations over multi-kilometer rover traverses sampling a range of geologic and geomorphic units. For example, the Mars Science Laboratory (MSL) has over ten instrument packages from fixed point weather instruments (REMS), remote imagers (NAVCAM, MASTCAM), remote chemistry laser ablation (CHEMCAM), crystallographic and geochemical analytical instruments (CHEMIN, SAM), and contact science instruments (microscopic imager (MAHLI), alpha particle x-ray spectrometer (APXS), drill) with resolutions from centimeters to tens of microns. Coupled with this is an unprecedented orbital mosaic composed of 25 cm/pixel visible imagery, hyperspectral chemical data, as well as a 1m/pixel digital elevation model (DEM) covering the landing ellipse and main science area in totality. Over two Earth years, MSL has sampled nearly 2000 individual targets coupled to over ten thousand unique science observations. Longer traverses like the Mars Exploration Rover (MER) Opportunity, have science observations spread over 40+ kilometers and greater than a decade in time! Precisely locating this scientific data down to millimeter accuracy on the surface of a Mars, or any planet, can take weeks to months or years and several personnel. Valuable spatial relationships can remain hidden from scientists and engineers in the interim, resulting in loss of mission performance on tactical (i.e. daily) and strategic (weekly to monthly) timelines.

Objective: Our goal is to develop a multi-mission geographic information system (MMGIS) with geospatial data standards, tools, and interfaces for accessing science instrument data as maps and other visualizations in near-real time (i.e. daily). This will be achieved by automating the localization/georeferencing of science data results and providing a unified mapping interface.

From such a system, we expect to:

- *Reduce Mission Operations cost and risk* – reduce processing time and improve scientific cross-comparisons between instruments.
- *Leverage technological advances and emerging standards* – inproving upon static maps, provide web-enabled map content for all instruments using a combination of commercial-off-the-shelf (COTS) and free open-source software (FOSS) across multiple computer platforms (PC, mobile).
- *Broaden Support for Future Missions* – standardize geospatial position of landed and rover instrument science data.

We also expect to leverage the following benefits:

- Decrease time required to localize science instrument data products from months to minutes.
- Improve communication between instrument teams in regards to observations planned and received.
- Increase science understanding within the mission for better science return and faster analysis.

Description of tasks and current state: MMGIS development has three main tasks to accomplish:

1. **Define data labels and methodology** for localizing any in-situ science instrument data to a planetary surface**.**

Current data labels vary from some to little localization information. For example, CHEMCAM data provides azimuth, elevation, and range to a target for each observation, but no standard xyz on the surface in any reference frame (i.e. rover, local level, or Mars). Instruments on the rover arm only provide joint arm angles. We can calculate position from these measurements, but no standard workflow is in place.

2. **Automate localization for any instrument** type or platform (e.g. fixed position, moveable instrument mast, robotic arm, sub-aerial platform).

We've developed methodologies and some scripts for localizing/georeferencing science instrument data, mostly by tying spacecraft clock (SCLK) data labels to rover localization via PLACES (see abstract Deen et al., this workshop) or using the mission target database as a proxy for instrument sample location for all observations. This approach is tractable, but imperfect in capturing the true resolution, especially for instruments like CHEMCAM whose laser shots are separated by only millimeters. This process requires instrument teams to provide additional information of target name associated with data records, sometime taking days, weeks, or months after observations are complete.

3. **Develop a mapping interface** useable by science and engineering teams to quickly assess and utilize recent results.

The MSL mission utilizes Environmental Systems Research Institute (ESRI) ArcGIS, a COTS software package that is common across U.S. federal agencies, many universities, and private companies. While being widely used, it has a steep learning curve, expensive to purchase (though somewhat ameliorated by site licenses at large organizations). In addition, the combination of orbital and in-situ datasets are tens of gigabytes in size presenting a difficulty in transferring to end-users, as well as properly accessing various spatial data types (8 and 32 bit raster data, point, line and polygon vectors with different stylings).

User capability is varied with some users wanting the raw data and others relying on static maps (e.g. Figure 1) for access, though everyone wants/needs instrument data in a spatial context to improve observations. We attempt to provide maps and localized data for science and engineering team members, but it can be time intensive for even simple queries (e.g. “Where are all the targets for the last two days? What’s the elevation at each one? How many were APXS?”) much less advanced ones (“What's the horizon mask for these locations?”). While we’ve automated some map generation, others require customization.

MMGIS interface, current and future development: We took advantage of COTS software to rapidly develop and deploy a test MMGIS using localized target and orbital data from MSL (Figure 2). This uses an Adobe FLEX interface that provides numerous premade tools for a robust interface. However, this interface is not mobile friendly and would prove difficult to make it so. Our current development is looking to use javascript tools which are multi-platform and mobile friendly. Initial results are promising using ESRI.js which ties in directly to our image tile server (ArcServer) and is friendly to our Mars map projection. Our ultimate goal is using only free open source software (FOSS) like Python, Leaflet (leaflet.org), Mapbox (mapbox.com), or D3 (d3js.org) for all MMGIS functionality. However, we’ve found that the current FOSS javascript tools are very Earth-centric requiring either a) modification of the code or b) ‘faking’ data projections to look like Earth, or c) development of complex methodologies for making the tools access non-Earth data.

Future Work: We hope to develop the MMGIS standards, methodologies, and mapping interfaces from the ideas and prototypes presented into a functioning framework for upcoming missions like InSight, Mars2020, the Europa orbiter and others. This nascent work will help guide us to interface with future instrument teams to develop spatially-enabled data labels, develop the necessary georeferencing pipelines, and accessible webgis front-end to all science data whether from orbit or in-situ.

Figure 1: Mars Science Laboratory (MSL) science target localization map.

Figure 2: Flexviewer style webgis front end.

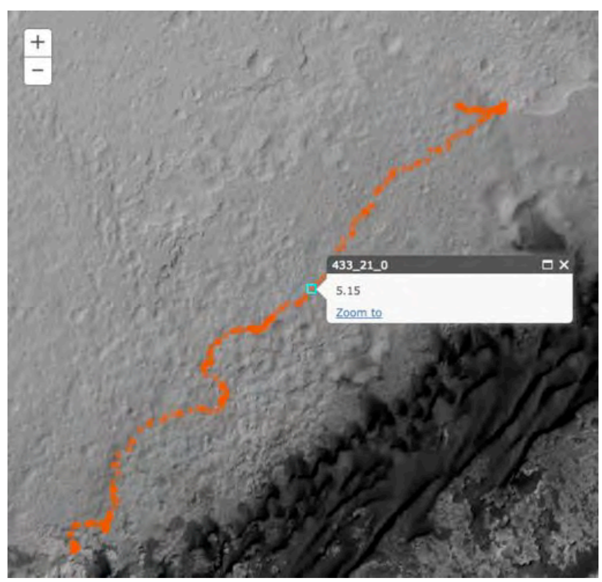


Figure 3: Prototype ‘slippy’ map using ESRI Javascript with ArcServer as a backend image tile server.

Marsviewer: Public Release and PDS Data.

R. G. Deen[1], N. T. Toole[2], and S. S. Algermissen[3]; [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Bob.Deen@jpl.nasa.gov, [2]same, Nicholas.T.Toole@jpl.nasa.gov, [3]same, Stirling.S.Algermissen.jpl.nasa.gov.

Introduction: Marsviewer is an image viewing tool tailored to Mars in-situ missions. It makes it easy to view original images (EDR's) as well as all derived image products (RDR's), such as XYZ maps, slope, reachability, mosaics, etc. Originally designed as a QC tool for the MER image processing team, it sees wide use throughout the MER, MSL, and PHX operations and science teams (with InSight and Mars 2020 coming soon).

Remote Access: Historically, Marsviewer required access to the image data store via local disk. This meant it had to run on the operational workstations. Remote access was only possible via X-windows, which was a significant limiting factor.

Leveraging off the Webification (w10n) protocol [1,2], Marsviewer, which is a Java application, is now able to run locally on any computer (Mac, PC, or Workstation). Data is accessed remotely off a w10n server, meaning that all user interaction can be local.

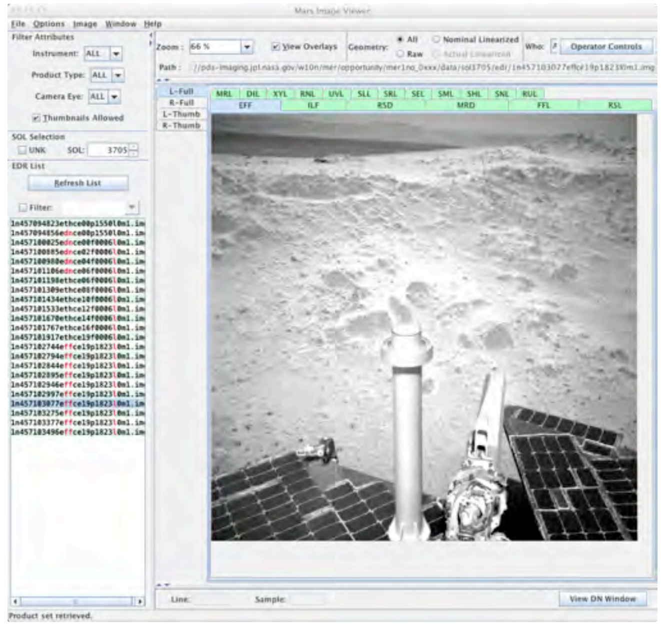
This remote access version has been deployed to the MSL operations team, and deployment to MER and InSight are in progress.

Web Marsviewer: In addition to the remote version of the Java client, we have recently developed a Web app version of Marsviewer. Written in JavaScript, this version requires no installation and works off most modern browsers. It communicates with a w10n-compliant web service that presents a mission-independent virtual file system, rather than reflecting the physical file system. This version has also been deployed to the MSL operations team, in a beta test form.

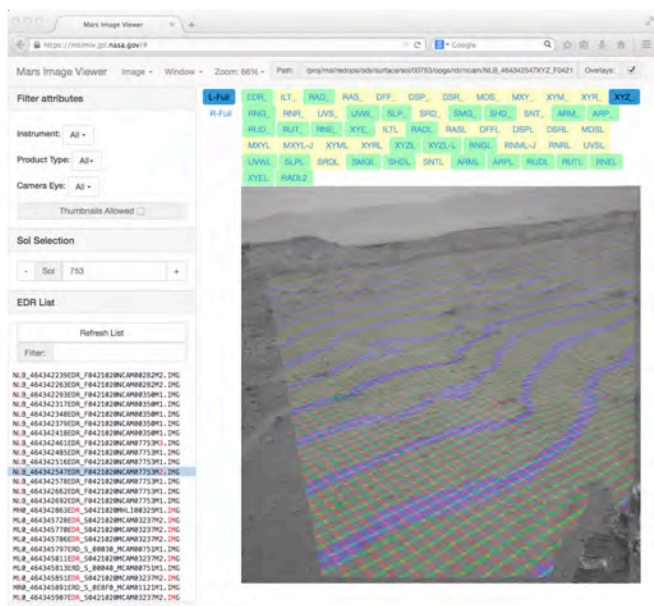
PDS Public Data Access: The PDS data archive is now accessible via a w10n server, meaning that all functionality of Marsviewer is available to visualized Mars lander and rover data in PDS (for MER, PHX, and MSL). As such, we are now releasing the Java version of Marsviewer to the general public [3]. For the first release, the MMM (Mastcam, MAHLI, MARDI) cameras on MSL are not supported, but those will be coming soon.

References:

[1] http://data.jpl.nasa.gov/earth-help
[2] http://w10n.org
[3] http://pds-imaging.jpl.nasa.gov/tools/marsviewer



Remote Marsviewer viewing PDS data from Opportunity, Sol 3705.



Web Marsviewer showing MSL data from Sol 753, with XYZ overlay.

Pointing Correction for Mars Surface Mosaics. R. G. Deen[1], S. S. Algermissen[2], N. A. Ruoff[3], A. C. Chen[4], O. Pariser[5], K. S. Capararo[6], and H. E. Gengl[7]; [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Bob.Deen@jpl.nasa.gov, [2]same, Stirling.S.Algermissen@jpl.nasa.gov, [3]same, Nicholas.A.Ruoff@jpl.nasa.gov, [4]same, Amy.C.Chen@jpl.nasa.gov, [5]same, Oleg.Pariser@jpl.nasa.gov, [6]same, Kris.Capraro@jpl.nasa.gov, [7]same, Hallie.E.Gengl@jpl.nasa.gov.

Introduction: The Multimission Image Processing Lab (MIPL) generates a significant volume of mosaics in support of Mars mission surface operations (for MSL, MER, and Phoenix, as well as InSight and Mars 2020). Quicklook mosaics use the raw camera pointing (as determined by encoders or resolvers) to get a mosaic that is close to correct. However, pointing knowledge errors (as well as uncorrectable parallax) lead to seams between the frames of a mosaic, or errors in coregistration between images taken by different cameras. [1]

This poster will describe the pointing correction process used by MIPL to reduce or eliminate these seams, and present several examples of how this process is used in practice.

Pointing Correction: The pointing correction process uses tiepoints between the frames, which can be derived automatically or by hand. These tiepoints are used in a bundle-adjustment process to minimize error by adjusting the pointing of the cameras (and/or the surface model) and re-computing the tiepoint error. This process will be described.

A recent innovation is the use of "miss distance" tiepoints as an error metric. This new type of tiepoint replaces the line/sample pixel-space error with the distance in XYZ space between the projected rays of the left and right tiepoints. This eliminates reliance on the surface model, which should be better for correcting pointing of 3D terrain meshes.

Corrected Mosaic Examples: Examples and use cases of pointing corrected mosaics will be presented. These may include (space permitting):

- Post-drive navcam mosaics [2]
- Cross-instrument coregistration
- Drive-direction mastcam/navcam combos
- Arm-camera mosaics
- Mastcam "gigapan" (RockNest) [3]
- XYZ mosaics
- Correction using miss-distance tiepoints

References:

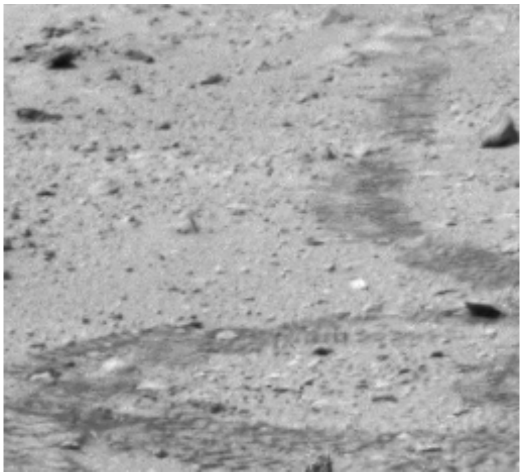
[1] Deen, R.G., "In-Situ Mosaic Production at JPL/MIPL", poster from 1st Planetary Data User's Workshop, Flagstaff, AZ, 2012.

[2] http://mars.nasa.gov/msl/multimedia/mosaics/

[3] http://mars.nasa.gov/multimedia/interactives/billionpixel/

Portion of pointing-corrected Navcam mosaic, MSL Sol 548

Portion of raw (uncorrected) MSL Sol 719 mosaic showing geometric seam (note the "doubled" features down the middle of the image).



Same mosaic after seam correction.

VICAR Open Source Release. R. G. Deen[1], S. C. Mayer[2], E. M. Sayfi[3], C. Radulescu[4], S. R. Levoe[5]; [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Bob.Deen@jpl.nasa.gov, [2]same, Shari.C.Mayer@jpl.nasa.gov, [3]same, Elias.M.Sayfi@jpl.nasa.gov, [4]same, Costin.Radulescu@jpl.nasa.gov, [5]same, Steven.R.Levoe@jpl.nasa.gov.

Introduction: VICAR (Video Image Communcation and Retrieval) [1] is an image processing system developed at JPL. It is used primarily but not exclusively for planetary image processing. With origins in the 1960's [2], it is still used on a daily basis today to support missions such as MER, MSL, and Cassini.

Open Source: We are pleased to announce at this conference that the core of VICAR is being released as Open Source software.

This core consists of the infrastructure, image I/O routines, parameter processing, image display, file format conversion, and most of the general purpose application programs (almost 350).

Not being included at this time are the mission-specific programs (such as the Mars-specific programs) or the telemetry processors (due to ITAR concerns).

Highlights of the release include:

- Almost 350 application programs covering general image processing (stretch, warp, map projection, statistics, filtering, mosaicking, label maipulation, etc).
- "xvd" image display program [3]
- File format conversion ("transcoder") [4]
- VICAR-format image I/O library, in both C and Java versions [5]
- IBIS (Image-Based Information System) for working with tabular data [6,7]
- Command-line parsing, plus optional command-line environment (TAE)

This release of VICAR is officially tested on Linux (32-bit) and Solaris platforms. It also builds and runs on Linux (64-bit) and Macintosh OS-X systems.

The poster will describe more about the contents of VICAR as well as highlight its history and uses.

Location for obtaining VICAR is TBD as of this writing but will be posted when ready on the VICAR web page [1].

References:

[1] http://www-mipl.jpl.nasa.gov/external/vicar.html

[2] Billingsley, F. et al, "VICAR-Digital Image Processing System", NASA Tech Briefs, NPO-10770, June 1, 1969.

[3] Deen, R.G. at al, "XVD Image Display Program", NASA Tech Briefs, NPO-46412, Sep 1, 2009 .

[4] Levoe, S.R and R.G. Deen, "Metadata-Preserving Image File Format Conversion", poster from 1st Planetary Data User's Workshop, Flagstaff, AZ, 2012.

[5] Deen, R.G. and S.R. Levoe, "Java Image I/O for VICAR, PDS, and ISIS", NASA Tech Briefs, NPO-47184, Feb 1, 2011.

[6] Stanfill, D.F. and M.A. Girard, "VICAR/IBIS Software System", NASA Tech Briefs, NPO-17081, Oct 1, 1988.

[7] Bryant, N.A. and A.L. Zobrist, "Image-based Information, Communication, and Retrieval", NASA Tech Briefs, NPO-14893, Sep 1, 1980.

Localization of MSL and MER: Methods and Data. R. G. Deen[1], F. J. Calef[2], T. J. Parker[3], and H. E. Gengl[4]; [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Bob.Deen@jpl.nasa.gov, [2]same, Fred.Calef@jpl.nasa.gov, [3]same, Timothy.J.Parker@jpl.nasa.gov, [4]same, Hallie.E.Gengl@jpl.nasa.gov.

Introduction: Localization is a process by which landing sites and rover positions are accurately determined on a planetary surface. Accurate positions are necessary for navigating the rover (avoiding hazards and getting to interesting locations), and to provide the proper scientific context for observations (using orbital imagery).

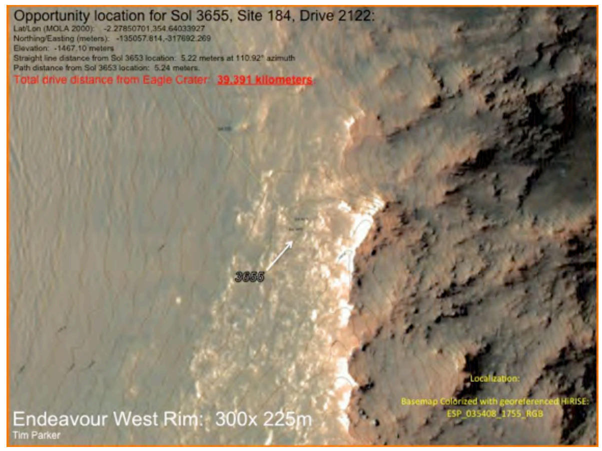
MSL and MER both attempt to keep track of their location as they drive by combining wheel revolution counts, yaw, and visual odometry (VO) [1]. VO is quite accurate, but it consumes precious resources (time and power) so it is only done when precision is needed onboard. Counting wheel revolutions does not take into account wheel slippage and thus can be significantly off. Even VO is subject to accumulation of errors over long traverses. Therefore, localization must be done on the ground by comparing the rover's *in-situ* view to orbital views in order to get precise positions.

This talk will describe how localizations are done by the MER and MSL Localization Teams, how the resulting data are managed, and how to find and use this data in PDS.

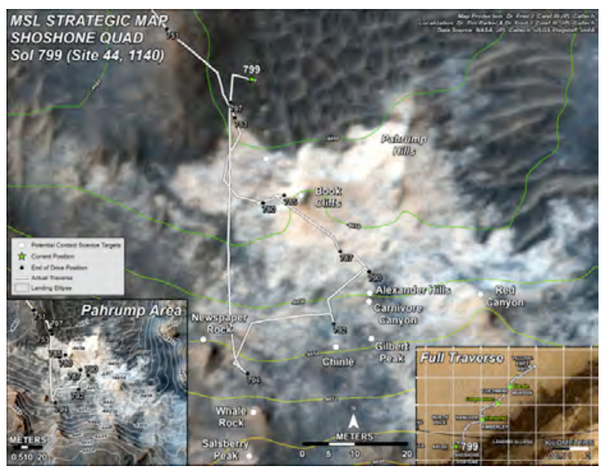
Localizing the Rover: The rovers are localized by taking orthorectified navcam mosaics and comparing them to orbital imagery. This process will be described in detail.

Managing the Data: The localization results are stored in the PLACES (Position Localization and Attitude Correction Estimate Storage) database, a ReST-style database accessed via URL's. This database stores localization from any and all sources, letting the user determine which localizations they want to use. This database will be described, as well as current work towards a more user-friendly front end.

Finding and Using the Data: The PLACES data for MSL is now available in PDS [2]. This data will be described, as well as how to find it in PDS. Additionally, some examples of how PLACES data is used will be presented. MER localization data is not yet available in PDS, but we are working towards this as a goal.



Sample localization report for Opportunity (Sol 3655).



Sample traverse map for Curiosity (Sol 799)

References:

[1] Maimone, M., Y. Cheng and L. Matthies, "Two Years of Visual Odometry on the Mars Exploration Rovers," Jour. Field Robotics: Special Issue on Space Robotics 24(3), pp. 169-186, March 2007

[2] http://pds-imaging.jpl.nasa.gov/data/msl/MSLPLC_1XXX

COMPARISON OF DIGITAL TERRAIN MODELS DERIVED USING DIFFERENT TECHNIQUES D.N. Della-Giustina[1], E.K. Kinney Spano[1], M. Chojnacki[1], S. Sutton[1], University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, USA (danidg@orex.lpl.arizona.edu).

Introduction: In preparation for the OSIRIS-REx Sample Return Mission we examine newly available computer vision and traditional photogrammetry tools capable of producing digital terrain models (DTMs) from stereo imagery. DTMs are essential for terrain analysis in geomorphology and physical geography, and can often provide much higher resolution surface information than whole-object shape models. These terrain models, along with imagery analysis, can be used to understand planetary surface processes. In this work we present the results of a comparison of photogrammetry tools for DTM production.

Stereophotogrammetry is a technique that has been used to determine the topography of many Solar System bodies [1]. Characterizing the terrain and elevation with images taken by the OSIRIS-REx Camera Suite (OCAMS) is a requirement for the OSIRIS-REx Mission, which will survey and sample asteroid (101955) Bennu in 2019 [2]. Understanding the topography of the sample site will be of chief importance—the OSIRIS-REx Touch And Go Sample Acquisition Mechanism (TAGSAM) can only interface with terrain that meets specific slope and regolith aggregate-size thresholds.

To prepare for the OSIRIS-REx sampling event, we are performing a relative comparison between DTM extraction techniques. We examine DTMs produced by two commercial photogrammetry packages: PhotoScan (distributed by AgiSoft LLC) and SOCET SET ® (distributed by BAE Systems, Inc [3]). SOCET SET is a traditional photogrammetric toolbox capable of determining terrain from images taken at different resolutions using a suite of algorithms. PhotoScan is a close-range 3D reconstruction package that has been used successfully for terrestrial aerial photogrammetry applications [4-7].

Methods: SOCET SET has been successfully used to derive DTMs using stereo-imagery from several NASA missions. These methods are well described in the literature [1].

PhotoScan, on the other hand, is a relatively new software package. The literature only describes the applications of PhotoScan for aerial imagery [4-6] and close-range 3D object reconstruction (archaeology) [6-7].

Unlike traditional photogrammetry tools PhotoScan is well suited for deriving 3D information from oblique imagery. PhotoScan achieves this by using the scale-invariant feature transform (SIFT) algorithm [8] for automated tie-point detection in both nadir and oblique imagery. Using SIFT, PhotoScan is able detect tie-points (keypoints) more rapidly than other techniques (including human decision making). SIFT keypoints are used to align the photos in a first step to produce a sparse point cloud. After measuring the ground control points, a bundle adjustment is performed to produce a dense point cloud [6]. Photoscan will refine the solution by calculating the reprojection error of a SIFT keypoint [6].

Results: Using MESSENGER MDIS images of Mercury, we have generated DTMs from the same set of stereo-images using both SOCET SET and PhotoScan. We co-register these DTMs and re-sample to ensure a common domain. We then determine the absolute difference and root-mean square difference between the datasets. We report the results of this comparison, highlight areas of significant difference between each DTM, and account for these differences in terms of the merit of each technique.

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JMARS - Easy Visualization and Analysis of Planetary Remote Sensing Data S. Dickenshied[1], S. Anwar[1], D. Noss[1], W. Hagee[1], S. Carter[1], [1]Mars Space Flight Facility, 201 E Orange Mall, Arizona State University, Tempe, AZ 85287 USA.

Introduction: JMARS is a geospatial information system developed by ASU's Mars Space Flight Facility to provide mission planning and data-analysis tools for NASA orbiters, instrument team members, students of all ages, and the general public. Originally written as a mission planning tool for the THEMIS instrument onboard Mars Odyssey, JMARS has since been released to the science community and the general public as a free tool to quickly locate and view planetary data for Mars, the Moon, Vesta, Ceres, Mercury, Earth, and many of the outer planet moons.

JMARS is actively used as a mission-planning tool for NASA instruments orbiting Mars and the Moon and will be used to target all of the science instruments on the upcoming OSIRIS-REx asteroid sample return mission. JMARS is also used as a visualization tool by numerous current and future NASA missions including THEMIS, MRO, LRO, Dawn, and OSIRIS-REx.

The public version of JMARS offers quick access to hundreds of maps and millions of individual images collected from planetary missions. These images can be easily located by geographic area or filtered down based on any number of scientific parameters, then viewed in situ without excessively large downloads or extensive knowledge of planetary data formats.

Numeric data is preserved in JMARS whenever possible, allowing the user to draw a profile line to quickly plot elevation, mineral abundances, and temperature data, or project an entire scene over available topography to create a 3D image. Vector data can be imported or created on the fly, then combined with numeric maps to calculate and report separate values for each shape.

Current development efforts include adding support for displaying planetary data on complex shape models like Itokawa and Bennu, and extending all existing JMARS functionality to also work well in a 3D view.

If the built in analysis features are insufficient, JMARS provides a quick link to the official repository for each image, allowing the user to download and process data on their own.

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PROCESSING AND VISUALIZING PLANETARY DATA USING DAVINCI: UPDATES FOR PORTABILITY AND SCRIPTABLE EXECUTION.

C. S. Edwards[1], S. Anwar[2], W. Hagee[2], D. Doerres[2], S. Dickensheid[2], P. R. Christensen[2], [1]US Geological Survey, Astrogeology Science Center, Flagstaff, Arizona, 86001, cedwards@usgs.gov, [2]Arizona State University, School of Earth and Space Exploration, Mars Space Flight Facility, PO BOX 876305, Tempe, AZ 85287-6305.

Introduction: Images of planetary bodies in our solar system are some of the most widely utilized data products available to the planetary science community. These data have been acquired from the beginning of NASA's exploration of the solar system to the present day. Imaging cameras and spectrometers such as the Viking Orbiter Visual Imaging Subsystems (VIS) [1], the Mars Orbiter Camera (MOC) [2] wide angle and narrow angle instruments, the Thermal Emission Imaging Systems (THEMIS) [3, 4] visual and infrared imagers, the High-Resolution Stereo Camera (HRSC) [5, 6] visible imager, and the Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment (HiRISE) [7], Context Imager (CTX) [8], and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [9] have all provided new and unique views of the planet that have revolutionized the manner and detail in which Mars is studied. Additionally, high-resolution spectral data from the Thermal Emission Spectrometer (TES) [10] and CRISM have provided a wealth of mineralogical data which are widely used by the community to characterize the geology and planetary history of Mars [11].

Data Processing Tools: In this abstract, we present an open source toolkit developed by the Mars Space Flight Facility at Arizona State University that is used to calibrate, analyze, and visualize THEMIS data. Recently this toolkit has been applied to additional datasets [e.g. 12].

DaVinci (http://davinci.asu.edu) is an interpreted language that looks and feels a lot like C, but has additional vector oriented features that make working with large (multiple gigabytes) blocks of data significantly easier. This makes DaVinci well suited for use as a data processing tool, allowing symbolic and mathematical manipulation of hyperspectral data for imaging spectroscopy applications. DaVinci provides support for importing and exporting current Integrated Software for Imagers and Spectrometers (ISIS, http://isis.astrogeology.usgs.gov) data formats, among a variety of other data formats including VICAR, multiband GeoTIFF, CSV/ASCII and other commonly supported image formats (e.g. PNG, JPEG, BMP). DaVinci allows the end user to develop image-processing algorithms, query databases, and directly download images and maps of Mars, the Moon, and numerous other bodies all with an interactive scripting interface. Its plotting and image display capabilities let the user visualize the effect of data processing in real-time. Processing algorithms developed in DaVinci can be easily integrated with ISIS to provide a flexible compliment to the established ISIS routines. Additionally, DaVinci provides additional tools but complementary tools to ISIS that allow users to mosaic hundreds to tens-of thousands of images together with various levels of normalization and processing [13].

Feature Highlights and New Developments:

Standalone ISIS3 Readers: A major development in the past year for DaVinci is a stand-alone ISIS3 file reader that does not depend on the ISIS3 API. In the past, a full installation of ISIS and a user-compiled version of DaVinci were required to enable the I/O of ISIS3 files, creating a large barrier to its use. Recently we have developed a stand-alone reader that will be available on all supported operating systems (OS X, Debian/Ubuntu, RedHat/CentOS, and Windows). The ISIS3 writer is currently under development and is expected to be complete within the year.

JMARS-DaVinci Link: The Java Mission-planning and Analysis of Remote Sensing (JMARS, http://jmars.asu.edu) tool provides easy identification and correlation of various datasets and derived products. It allows data from all the instruments listed in the introduction (and datasets from other planetary bodies) to be viewed in either a map-projected or 3D shape model view (see JMARS abstracts [e.g Dickensheid et al.; Hagee et al.] at this workshop for additional information).

DaVinci can read data directly from the back-end of JMARS, manipulate it, and display the result in context with other datasets in JMARS. The DaVinci-JMARS link is a straightforward way for end-users to directly and quickly ingest their data for a single JMARS session or to be stored on the JMARS servers for delivery to any JMARS instance. Users with access to Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data of the Earth can process, stretch, and perform spectral mixture analysis results that can be viewed in JMARS without outputting a geo-referenced file. The back-end link in JMARS is not specific to DaVinci, relying on a standard web-based protocols and can be readily modified for users of ENVI/IDL or other image processing toolkits such as those developed for Python.

Geospatial Data Using DaVinci and GDAL: DaVinci utilizes a script library that leverages on the

Geospatial Data Abstraction Library (GDAL). This suite of functions provides the ingestion of raster and shape (e.g. polygon, point, line etc.) files while preserving geospatial information. This suite of functions permits the projection of unprojected data from ground control points, the reprojection of data (raster and shape) from one projection to another (including projection matching), the rasterization of shapes, the reading of ~30 additional file types supported by GDAL and the writing of multi-band GeoTIFFs. All projection and file I/O is handled by GDAL so updates and improvements made by the highly active GDAL/PROJ open source community are directly available to DaVinci. This set of geospatial aware functions also integrates directly with the aforementioned JMARS-DaVinci link.

Stand Alone THEMIS Processing:

A large volume of literature has been published utilizing advanced image and data processing algorithms designed for the compositional analysis of THEMIS and TES data. Publications that utilize DaVinci explicitly include: 1) TES atmospheric correction [14], 2) THEMIS atmospheric correction and instrument calibration [15], 3) THEMIS calibration, line correlated, and uncorrelated noise removal algorithms [13], and 4) mineral abundance determinations [e.g. 16, 17-26]. The data processing steps to both mosaic and utilize well calibrated THEMIS data are presented by *Edwards et al.* [13].

However, these steps rely on a complicated sequence of commands that include reading and writing files, querying databases, use of ISIS commands, etc. We have developed a suite of stand-alone processing scripts that are now distributed with every version of DaVinci and significantly streamline the processing of THEMIS data. These commands are automatically updated when DaVinci's “script library” is updated and once the user includes the executable path in their standard path, are useable on the command line from any directory. These scripts include: 1) pre-projection processing, 2) post-projection processing, 3) visualization processing and GeoTIFF generation for easy importing into the user’s tool of choice. These 3 steps (and ISIS projection steps) are wrapped in a processing script which executes a set of user-configurable defaults and will carry out the process defined in *Edwards et al.* [13] with no user input. While automatic atmospheric correction is under development [e.g. 27] and is not deployed yet, it will be incorporated in this pipeline as soon as it has completed validation.

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Lunaserv WMS – A Planetary GIS Server N. M. Estes, C. D. Hanger, A. Ramaswamy, E. Bowman-Cisneros, M. S. Robinson, School of Earth and Space Exploration, Arizona State University, nme@ser.asu.edu

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) Science Operations Center (SOC) operates the LROC camera, processes LROC observations, generates mosaics, maintains the LROC Planetary Data System (PDS) data node, and performs a wide variety of work using LROC observations. In support of these activities, the LROC SOC needed a way to get map data into JMARS [1], web sites, Geographic Information System (GIS) software, and generate and combine map data for other uses as well. To solve these needs, the LROC SOC first looked at existing Web Map Service (WMS) software packages. The existing WMS software at the time had various limitations including issues with global map data, no support of non-Earth Spatial Reference Systems (SRS), and performance issues with millions of observations, so the LROC SOC started development of Lunaserv in 2009 to create a WMS compatible server software supporting IAU2000 planetary SRS [2], and capable of serving the large amount of LROC data.

The first version of Lunaserv supported only the orthographic projection, and only in the Moon's coordinate system. Subsequent development enabled Lunaserv to support arbitrary projections for any planetary body. The LROC SOC released Lunaserv as open source in 2013 making Lunaserv available to anyone for serving planetary data using the WMS standard [3].

Capabilities: Lunaserv implements the Open Geospatial Consortium (OGC) WMS standard. The WMS standard was chosen because it is a protocol widely used by a variety of GIS software including QGIS, ArcGIS, Grass, OpenLayers, Leaflet, and JMARS. By using the WMS standard, Lunaserv can provide map data for the largest possible set of GIS data users from a single set of source data [4].

The WMS standard allows for map data to be rendered in a variety of formats, and in any SRS understood by the WMS server. A WMS SRS specifies

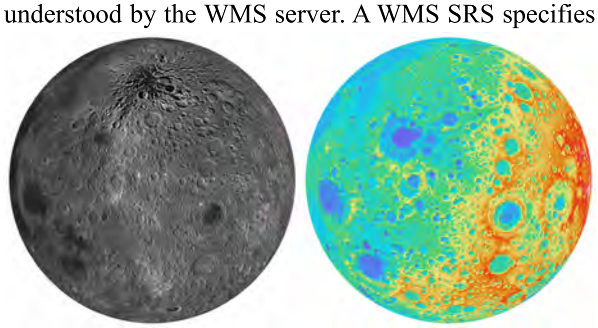

Figure 1: The Moon rendered in an orthographic projection centered at 45° N, 120° E. The left is a LROC WAC global mosaic, and the right is a color shade based on the GLD100 [11].

the combination of projection and planetary body spheroid [5]. While the WMS specification recognizes only Earth-based SRS definitions, Lunaserv additionally supports the IAU2000 planetary SRS definitions, and any arbitrary SRS that can be defined using the proj.4 library [6].

Lunaserv supports a variety of geographic data types.

- Raster Data (8-bit) (Fig. 1)
  - Regional
  - Global
- Vector Data (Fig. 2)
  - Points
  - Line-strings
  - Polygons
  - Annotations
  - Grids
- Illumination (Fig. 3)
  - Day/Night Shading
  - Topography-based
- Numeric (32-bit) (Fig. 4)

The raster types are loaded from pyramidal TIFFs (PTIFF). These PTIFFs can either have embedded geographic meta-data, or the geographic meta-data can be specified in a separate file. The PTIFFs can also have a 1-bit mask file to specify the area of interest within the PTIFF that should be rendered. The PTIFFs for a given layer can either be listed in the layer's configuration file, or the list can be loaded from a database.

The vector types are loaded from flat files, shapefiles, or a database.

Lunaserv supports the PostgreSQL database by default, but support for other databases is possible. All database operations support a rich set of filtering capabilities and can also used a predetermined set of 5° bins to limit the query results to the area of interest.

The illumination types render the requested illumination dynamically based on the sub-solar point

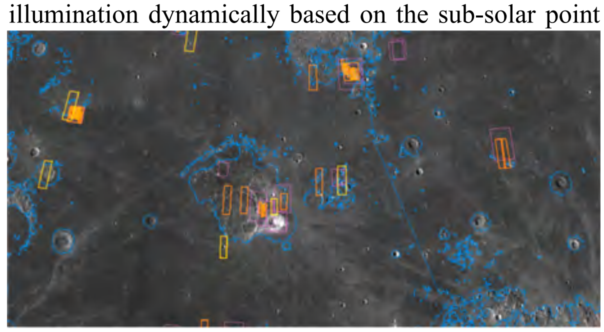

Figure 2: WAC global mosaic with ROI, DTM, Anaglyph, and shapefile RDR product layers overlaid as examples of vector layers.

calculated using the NAIF Spice toolkit [7]. For topographic-based illumination, a Digital Terrain Model (DTM) in the form of a 32-bit Integrated Software for Imagers and Spectrometers (ISIS) cube file is used to provide the necessary elevation data [8]. The illumination types will render the current illumination conditions by default, or will render the illumination conditions for any provided time or latitude/longitude sub-solar point.

The numeric type renders high-precision data types as either a 32-bit TIFF for most clients or as a 32-bit VICAR for JMARS. The source of the high-precision data is an ISIS cube. Multiple ISIS cubes of different resolutions can be provided, and Lunaserv will render each request using the ISIS cube that is the most appropriate resolution for the map request.

Usage: The LROC SOC uses Lunaserv to provide data for operations, data portals, web site context maps, PDS web interface, Where is LRO, digitizing, video generation, and other activities [9]. In addition to the ways Lunaserv is utilized by the LROC SOC, Lunaserv is also used by external users for visualization and research using a variety of GIS software packages. The public Lunaserv hosted by the LROC SOC contains all of the LROC map projected PDS products. For demonstration purposes, it additionally serves base imagery, illumination and nomenclature for Mercury, Venus, Earth, Mars, Io, Ganymede, Europe, Callisto, Rhea, Tethys, Iapetus, Dione, and Enceladus. Based on log file analysis, Lunaserv has been used by other researchers, students and the public with QGIS, ArcGIS, Google Earth, OpenSceneGraph, OpenLayers, and Leaflet [10]. On average, the public Lunaserv service hosted by the LROC SOC handles more than 20k map requests per day, and during periods of high activity, has handled over 600k map requests in a single day.

In addition to the usage of the LROC SOC hosted Lunaserv server, Lunaserv can also be installed and used by other groups to host their own map data.

Conclusion: The WMS protocol allows for GIS software users to easily combine data from multiple sources without first downloading or processing the data in any way. Lunaserv leverages this capability and extends it to provide support for the IAU2000 planetary SRS definitions, and provides support for large global data sets. By making data available using Lunaserv, research groups can make accessing their data faster and easier using software that many GIS users are already familiar with, and exposes the underlying data to uses not originally envisioned without developing custom protocols and applications.

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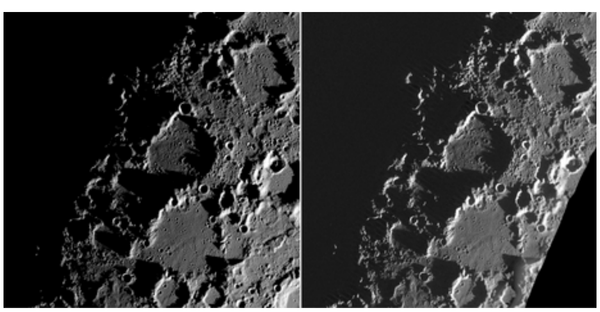


Figure 3: The north pole of the Moon on 2012-357. The left is a synthetic illumination map rendered by Lunaserv using the GLD100 DEM [11]. The right is a composite of actual LROC WAC observations from 2012-357.

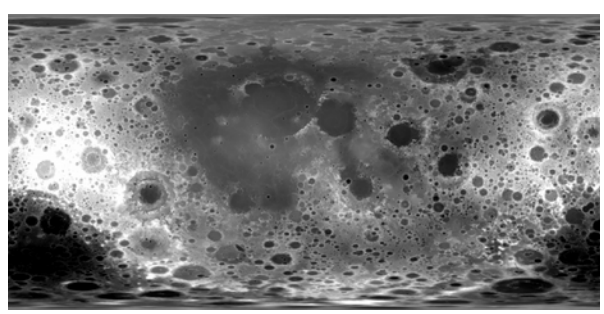


Figure 4: GLD100 DEM [11] rendered in simple cylindrical then converted to 8-bit for visual purposes using ENVI.

THE ROLE OF GIS IN GEOMETRIC PROCESSING OF NASA-DAWN/VIR SPECTROMETER DATA

A. Frigeri[1], M.C. De Sanctis[1], E. Ammannito[2], F. Tosi[1], F.Zambon[1], S. Fonte[1], M. Giardino[1], [1]Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, 00133 Roma, ITALY alessandro.frigeri@iaps.inaf.it; [2] Institute of Geophysics, University of California, Los Angeles, 603 Charles Young Drive, 3845, Los Angeles, CA 90095

Introduction: Between July 2011 and September 2012, the NASA-Dawn [1] mission acquired remote sensing data of Vesta from three different orbital heights [2]. In March 2015 Dawn has successfully entered orbit at Ceres, facing a year of data acquisition over the dwarf planet. Geographic Information System, initially developed for Earth-based environmental purposes, became more and more popular in the field of Planetary Sciences in the last 15 years [3]. Within the Dawn mission, Geographic Information System have been used widely within the scientific team, allowing a versatile high-level data exchange, the production of digital geologic maps and the spatial analysis of different scientific data, from crater densities to the distribution of different terrains and mineralogic species. Herein we present the experience of the use of GIS tools for the geo-processing of the spectrometer data coming from the VIR instrument onboard NASA-Dawn.

The spectrometer onboard NASA-Dawn: The Visible and InfraRed (VIR) instrument onboard NASA/Dawn is a hyperspectral spectrometer with imaging capability [4]. The design accomplishes entirely the Dawn's scientific and measurement objectives. In particular, the primary Dawn objective is the determination of the mineral composition of surface materials in their geologic context. The nature of the solid compounds of an asteroid (silicates, oxides, salts, organics and ices) can be identified by visual and infrared spectroscopy using high spatial resolution imaging to map the heterogeneity of asteroid surfaces and high spectral resolution spectroscopy to determine the composition unambiguously. The VIR Spectrometer covers the range from the near UV (0.25 μm) to the near IR (5.0 μm) and has moderate to high spectral resolution and imaging capabilities. It is is the appropriate instrument for the determination of the asteroid global and local properties. Two data channels are combined in one compact instrument. The visible channel covers 0.25-1.05 μm and the infrared channel covers 1-5.0 μm.

The maps of spectral paramter of Vesta: Ground based studies demonstrated that Vesta's mineralogy is dominated by pyroxenes [5], thus the pyroxene-related spectral parameters are particularly useful in mapping the mineralogic differences across the surface of Vesta. The process of mapping those single spectral parameter values over large areas allow for observation of the spatial variation of the mineralogic composition across the asteroid. The combined use of the Integrated Software for Imagers and Spectrometers (ISIS) [6, 7, 8] and the Geographic Resources Analysis Support System (GRASS) GIS [9, 10] allowed to mosaic the pyroxene-related spectral parameters extracted from VIR data acquired during the orbits of the Vesta campaign [11]. Figure 1 show the variation of pyroxene band II variation across the surface of vesta through a 15-quadrangle scheme.

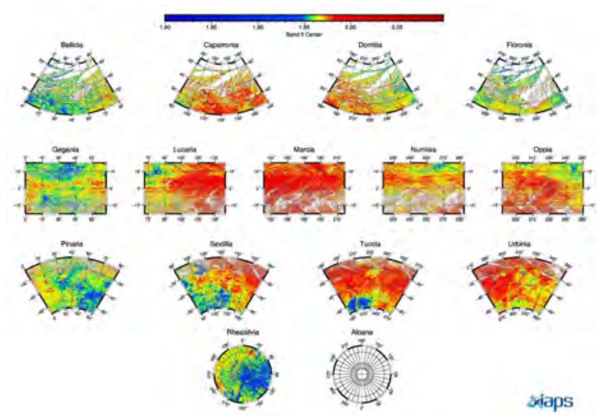
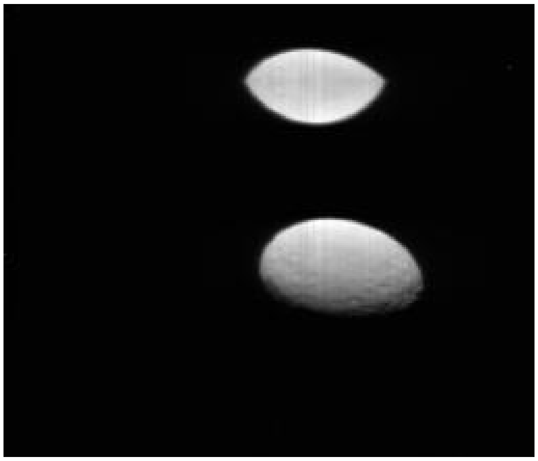
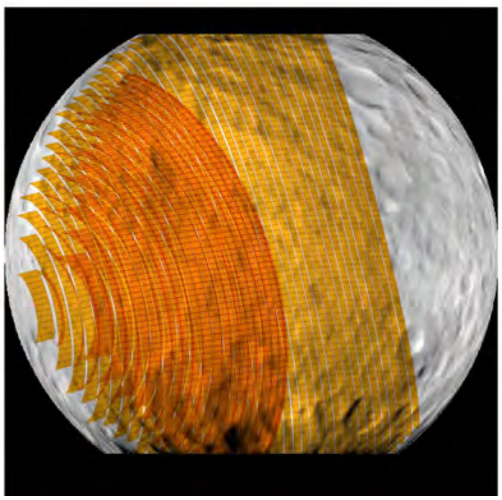


Figure 1: The pyroxene band II center maps, from the spectral parameters map of Vesta. Geoprocessing was made with ISIS and GRASS GIS. The color variation indicate clearly the mineralogic diversity across the surface of the asteroid.

VIR operations at Ceres: The data acqusition of VIR at Ceres becomes more complicated than on Vesta for two main reasons, which are closely related to each other. First of all Ceres is generally more dark than Vesta and this implies that longer exposure times are needed in order to have a sufficient signal to noise ratios. The second factor affecting the complexity of data acquisition over Ceres is that Dawn's ship orientation can not be controlled with the same accuracy used for Vesta. In fact, of four reaction wheels available on Dawn, two experienced problems during the mission, respectively in June 2010 and in August 2012 during the leave from Vesta. Since normal operations require three wheels, pointing at Ceres has to be adjusted by ion thrusting, loosing accuracy between the planned and the effective data acqusition geometries. The ion thrusting pointing adjustements affects the acquisition geometry of VIR, as shown in Figure 2.



(a) Level1B VIR data



(b) Projected VIR footprints

Figure 2: An example of VIR data acquired during thrust activation on Dawn at Ceres. (a): the Level1B data cube VIR_IR_1B_1_477629880 (band 100 of the infrared channel) shows the effect of change of pointing direction of the spacecraft. (b): the geometry of the footprints (orange) of the same data, projected over a Framing Camera image mosaic, the darker orange indicates areas with overlapping footprints. In this case we have 2 and 3-fold footprint's overlap within the same data cube.

Software improvements and the use of GIS at Ceres: The two factors indroduced above generate a special case which has to be handled specifically by the processing software. USGS's ISIS3 VIR implementation is planned to be improved, introducing a more accurate representation of the instrument footprints, taking into account the start and stop acquisition times. The change of acqusition direction during the thrusting can also cause topologic problems to some footprints. Within the VIR team we are using Geographic Information System (GIS) to handle geometries, as we did for producing spectral parameters mosaics for Vesta. This allows to geoprocess the correct geometries computed with SPICE [12] taking into account start and stop acqusition times, and to check the topology for every footprint. We develop a data model for the hyperspectral data footprints, that points to the spectra within the processed data cubes.

Discussion: Geographic Information System has been succesfully applied to various activities within the Dawn/VIR team. The range of application of geospatial processing spans from the technical/engineering operations to the scientific production. GIS-compatible digital maps are easily exchanged thanks to the use of open formats as the ones promoted by the Open Gis Consortium (OGC). After the successful use for the study of Vesta, we expect to make a more intensive use of the GIS procedures during the Ceres campaign.

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NEW ISIS SOFTWARE FOR WORKING WITH MOON MINERALOGY MAPPER DATA. L. R. Gaddis[1], R. Kirk[1], B. Archinal[1], K. Edmundson[1], L. Weller[1], S. Sides[1], J. Boardman[2], E. Malaret[3], and S. Besse[4]. [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ, 86001, USA (lgaddis@usgs.gov). [2]Analytical Imaging and Geophysics, LLC, Boulder, CO, USA. [3]Applied Coherent Technologies, Herndon, VA. [4]ESA/ESTEC, Noordwijk, the Netherlands.

Introduction. The NASA Moon Mineralogy Mapper (M^3) instrument returned hyperspectral data for ~95% of the Moon from the ISRO Chandrayaan-1 spacecraft [1-4]. The M^3 data are uniquely valuable for characterizing surficial water [2, 5] and surface mineralogy at high spatial resolution (140 m/pixel) at wavelengths to ~3.0 µm [6-9]. However, the archived M^3 data were processed with a preliminary global digital elevation model from the Lunar Orbital Laser Altimeter (LOLA) on the Lunar Reconnaissance Orbiter (LRO). The goal of this work is to use the higher spatial resolution (~100 m/pixel) and improved geodetic accuracy of the LRO Wide Angle Camera (WAC) stereo-derived topographic model [i.e., the GLD100 digital terrain model (DTM), 10] to improve the selenolocation of the M^3 data. Root-mean-squared (RMS) positional errors will be reduced from ~200 m relative and 450 m absolute to a pixel (~140 m) or better, and the many images with positional errors of kilometers will be corrected.

This project has several goals: (1) Reprocess M^3 data through the original mission's Level 1B (L1B) pipeline using the improved DTM to improve selenolocation accuracy; (2) Develop USGS ISIS3 software [11] for processing M^3 data (including a physically rigorous camera model); (3) Control the global M^3 dataset to obtain higher/known positional accuracy and generate new L1B products; (4) Reprocess L1B data through the mission's level 2 (L2) pipeline using the DTM to improve thermal and photometric accuracy; (5) Improve the photometric modeling; (6) Create orthorectified and mosaicked (Level 3) data products; and (7) Deliver interim and final products, including NAIF SPICE kernels [12] and calibrated, map-projected M^3 products to the Planetary Data System (PDS). Goals 1 and 2 have been completed and work is ongoing on goals 3, 4 and 5. *Here we describe the ISIS software tools developed and now available for working with M^3 data, and preliminary results of our restoration of the M^3 data using these tools and capabilities.*

ISIS Software. The USGS ISIS planetary cartographic software [11] is free to users (see http://isis.astrogeology.usgs.gov/) and it is used for this work because it supports rigorous physical modeling of the geometry of image formation from planetary cameras and the use of photogrammetric bundle-adjustment techniques to control images (***Figure 1***). The resulting cartographic products have precision and accuracy that is not only as high as possible but well understood and documented by statistical error estimates.

For working with M^3 data, ISIS software has been developed to support (1) ingestion of M^3 L1B data (both old and new products) using the ***chan1m32isis*** program, (2) creation of pointing, instrument, spacecraft, and frames kernels (CK, IK, SPK, and FK) from updated LOC (M^3 seleno-location) files, and (3) development of a camera model with characterization of optical distortion of the M^3 camera (used by the program ***spiceinit***). Information in the labels (e.g., the different resampling of data in the spatial and spectral dimensions in M^3 Global and Target Modes) is translated by the ingestion program to an ISIS-friendly format. The appropriate spacecraft position kernel (SPK, trajectory for an image) is associated with the frame, and an initial CK (pointing) kernel is computed from the LOC file. "No data" lines are inserted in the hyperspectral image cube where data are missing, previously truncated clock start and stop times are updated using NAIF SPICE library and spacecraft clock counts, and the preliminary CK and SPK kernels are revised to encompass the earliest start time and latest stop time. A reconstructed kernel database file supporting M^3 frame processing in ISIS is available as part of the April 2015 release of ISIS.

We are currently using these ISIS capabilities to generate improved spacecraft position and pointing data for M^3 and to support derivation of a rigorous solution of the camera pointing and generation of improved CK kernels. The M^3 camera model provides the ability to calculate image coordinates (line, sample) of a point in three dimensions or the reverse. A key part of the new ISIS camera model for M^3 is an improved optical distortion model that provides an accurate representation of the M^3 camera geometry in terms of physical parameters (i.e., boresight orientation, focal length, radial and decentering distortions).

The ISIS ***jigsaw*** program performs a bundle adjustment using tie point measurements from overlapping images to simultaneously refine image geometry (i.e., camera pointing, spacecraft position) and control-point coordinates (lat, lon, & radius) to reduce boundary mismatches in mosaics. Planned new *jigsaw* tools will provide an advanced adjustment capability that allows simultaneous improvement of the camera parameters and modeling of timing biases. Controlling the M^3 data with these tools is valuable as an independent check of the solution derived with the team processing pipeline, but this work also will improve the accuracy and precision of products to an extent that will be well documented by rigorous modeling of error propagation. A result of these new tools will be significantly updated SPK kernel data for M^3. New SPK data and other updated kernels for M^3 will be delivered to PDS and NAIF [12]. These data will document the position and pointing of the spacecraft at all phases of the mission during collection of M^3 data. This information has been lacking because of the loss of one and then both star tracker instruments during the mission, and errors in the spacecraft clock information.

Preliminary Results: The revised seleno-location process resulted in local per-pixel topography models that are overall improved but localized multi-pixel offsets remain. These will be addressed with detailed ISIS cartographic processing (***Figure 1***) of M^3 data in the coming year. As was the case in the original M^3 archived data in PDS, the OP1B data are the best behaved geometrically and most closely match the WAC mosaic and GLD100 DTM. The OP1A data appear equally well-behaved in our test mosaic, and the OP2A, B, and C data will likely need the most work to geometrically controlled. Although ISIS uses more automated, feature-based matching tools, control is primarily evaluated through an iterative process of orthorectification of images and examination of consistency of placement of overlapping images in map coordinates of test mosaics. We are working with a single wavelength (band 9, 750 nm) to establish and evaluate global control, but the results are expected to be fully applicable to the multiband M^3 dataset. The goal is to produce a geometrically improved hyperspectral mosaic of all M^3 Global Mode data, along with updated kernels and metadata.

Next Steps: In parallel with this geometric work, we are re-examining the photometric correction of the M^3 data with the goal of improving it. The photometric correction is based on imaging parameters derived from the GLD100 and is applied to the L2 data. We are researching application of the Hapke and Akimov photometric models [13]. Once a photometric model is selected, it will be applied to L2 data from which a thermal correction has been removed [e.g., 14].

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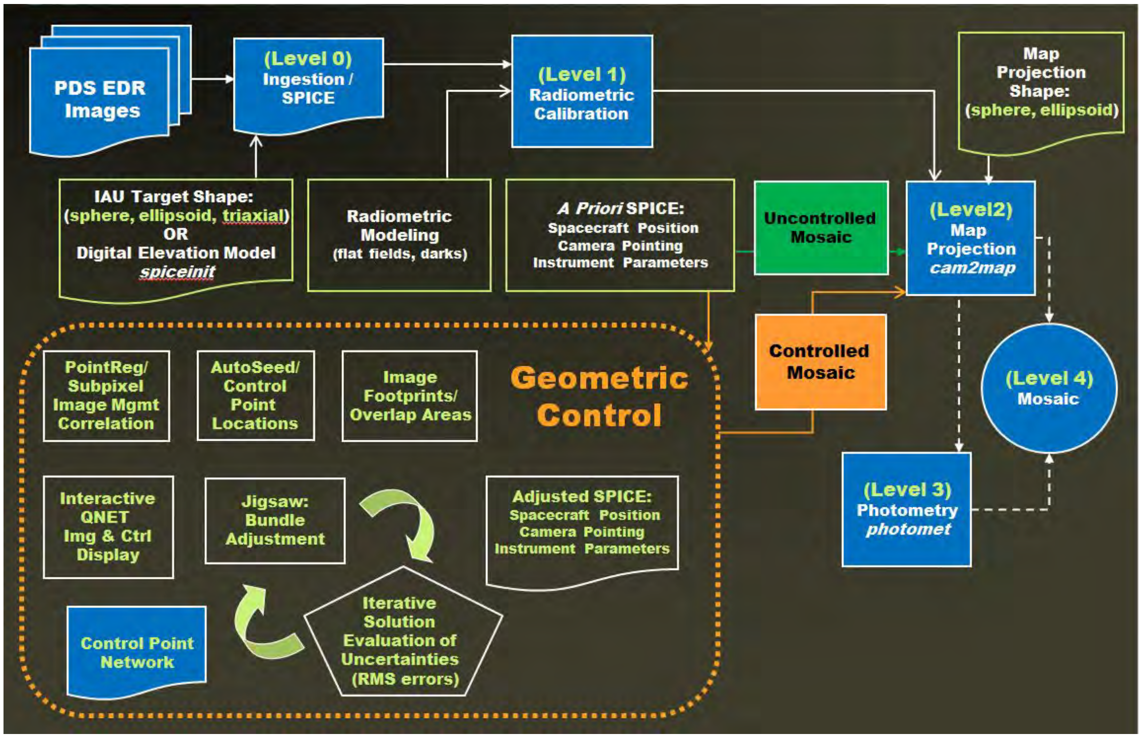
Figure 1. *Schematic view of end-to-end data processing in ISIS (after [14]). The "Geometric Control" steps are iterative and often extensively and multiply interconnected, but detail is not shown here. Thus far we have begun to create and evaluate uncontrolled M^3 mosaics in preparation for establishing a more rigorous single-band ~global controlled mosaic.*



USGS ISIS TOOLS SUPPORTING LUNAR SELENE "KAGUYA" DATA FROM TERRAIN CAMERA, MULTIBAND IMAGER AND SPECTRAL PROFILER INSTRUMENTS. L. R. Gaddis[1], J. Barrett, J. Laura, M. Milazzo. Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ, 86001, USA (lgaddis@usgs.gov).

Introduction. The Japan Aerospace Exploration Agency (JAXA) Selenological and Engineering Explorer (SELENE) "Kaguya" mission mapped the Moon in 2007-2009 [1]. Onboard SELENE was the Lunar Imager/Spectrometer (LISM) instrument package that housed the Terrain Camera (TC, [2]), the Multiband Imager (MI, [3]) and the Spectral Profiler (SP, [4]). The USGS Integrated Software for Imagers and Spectrometers (ISIS) [5] now provides ingestion support for these LISM instruments so that users can take advantage of further planetary cartographic data processing and visualization enabled by ISIS. Here we describe the capabilities of the currently available tools and our plans for future development.

SELENE "Kaguya" LISM Instruments: Along with laser altimeter, gamma ray spectrometer, magnetometer and other SELENE datasets, the Kaguya LISM data are available from the SELENE Data Archive Web site ([6], see http://l2db.selene.darts.isas.jaxa.jp/). TC data are available as Level-2 map-projected, tiled mosaics (4096 pixels/degree, 3x3 degrees in size) that have ~7.4 m/pixel spatial resolution and both morning and evening illumination. There are two versions of these data products, and a merged product with simulated vertical illumination ("ortho" data), for a total of five TC products. These data have also been mosaicked into near-global versions and released through the PDS Imaging Node Annex ([7], see http://astrogeology.usgs.gov/search/details/Moon/Kaguya/TC/Morning/v04/tc_mor_v04_global_64ppd/cub) at USGS. A tutorial for downloading these data from the Kaguya archive site is available at the PDS Imaging Node site (see http://pds-imaging.jpl.nasa.gov/portal/kaguya_mission.html). MI data are 9-band multispectral frames, with ~17 m/pixel (visible or VIS, 415, 700, 900, 950, 1000 nm) and 62 m/pixel (near-infrared or NIR, 1000, 1050, 1250, 1550 nm). The MI data are available from the Kaguya archive site as radiometrically calibrated, Level-2 coregistered frames that require cartographic processing, and as mosaicked, map-projected (MAP) versions that require mosaicking only. Radiometrically calibrated (Level 2B) Spectral Profiler data (500 m footprint, 140 m on the lunar surface; ~512-1676 nm for VIS and NIR1, 702-2588 nm for NIR2) were collected along the center of each MI frame, and these provide hyperspectral data for extraction of compositional data from lunar soils. A Level 2C product that has been photometrically corrected is also available [8].

Like the Clementine UVVIS and NIR data [9], wavelengths of the MI-VIS and -NIR cameras and Spectral Profiler were selected to maximize information on the mineralogy of the lunar surface [1, 10, 11]. For example, the MI data have been used to determine the global distributions of olivine-rich sites [12], purest anorthosite (PAN) sites [13], and pyroxene-rich sites [14]. Cross-calibrations among the SP VIS and NIR1 data, including comparisons to the Multiband Imager, Moon Mineralogy Mapper (M^3), and the Robotic Lunar Observatory [15-17].

ISIS Software. The USGS ISIS planetary cartographic software [5] is free to users (see http://isis.astrogeology.usgs.gov/) and is used worldwide by planetary scientists performing rigorous scientific research on image and spectral data from space missions. Several ISIS programs are now available for users working with the Kaguya LISM data.

TC data processing in ISIS: The ISIS program ***kaguyatc2isis*** allows users to import Level-2 TC data from the native JAXA archive format to an ISIS single-band cube format. (Note that the TC data are downloaded as "file.sl2" files; one must rename that to "file.tar" and use the Unix command *tar* to uncompress the data before ingesting the file into ISIS.) A user can select desired DN values for stretching or masking the data, and the ISIS program ***automos*** can be used to create mosaics of TC images of the lunar surface. The program ***kaguyatc2isis*** works for all five of the tiled TC frame products from the Kaguya archive.

MI data processing in ISIS: The ISIS program ***kaguyami2isis*** must be used to import Kaguya Level 2 MI frames into ISIS cubes. The VIS and NIR data are ingested separately, and then the ISIS program ***cubeit*** will allow users to combine data from both instruments into a 9-band, spatially coregistered cube that is tied to the TC data. The program ***kaguyami2isis*** accesses the ISIS camera model for the MI data, ensuring that proper camera attributes are included in the image labels, tests that it is ascending or descending data and spatially orients the files, trims excess data from band overlaps, and creates the labeled ISIS 9-band, multispectral cube. A user can select desired DN values for stretching or masking the data, and the ISIS program ***automos*** can be used to create mosaics of MI images.

For the MI map-projected (MAP) data, no camera model is required. The ISIS program ***pds2isis*** can be used to ingest the frame data and the program ***automos*** can be used to create multispectral mosaics. These can be displayed as single-band "albedo" views, as "natural" color products (bands 3, 2 1 as R, G, B), color-ratio composites [18], or used to derive rock-type thematic maps [19] or iron and titanium (wt. %) maps of the lunar surface [20, 21].

SP data processing in ISIS: The ISIS program ***kaguyasp2isis*** ingests a SP binary data file ("file.spc") to a tab-delimited text file. The program imports all of the available columns in the binary file (wavelength, radiance, reflectance, etc.) and all wavelengths (296 channels) from the VIS, NIR1, and NIR2 sensors. The user can limit the number of observations in the output as desired, but the program does not eliminate overlapping channels between sensors. Also, there is a "quality assessment" (QA) parameter that can be used to eliminate redundant channels, noisy bands, etc. (see p. 82 of the LISM_SPICE document for more information on QA: http://l2db.selene.darts.isas.jaxa.jp/help/en/LISM_SPICE_Fromat_en_V01-03.pdf).

Next Steps: Future work will address an expansion of capabilities for the ISIS software, especially for the SP data. Improvements for the latter will include application of the QA parameter to the imported SP observations, removal of redundant bands between sensors, and continuum-removal at user-selected wavelengths. If feedback is received on these tools and more capability is desired, we will seek additional funding to support further expansion.

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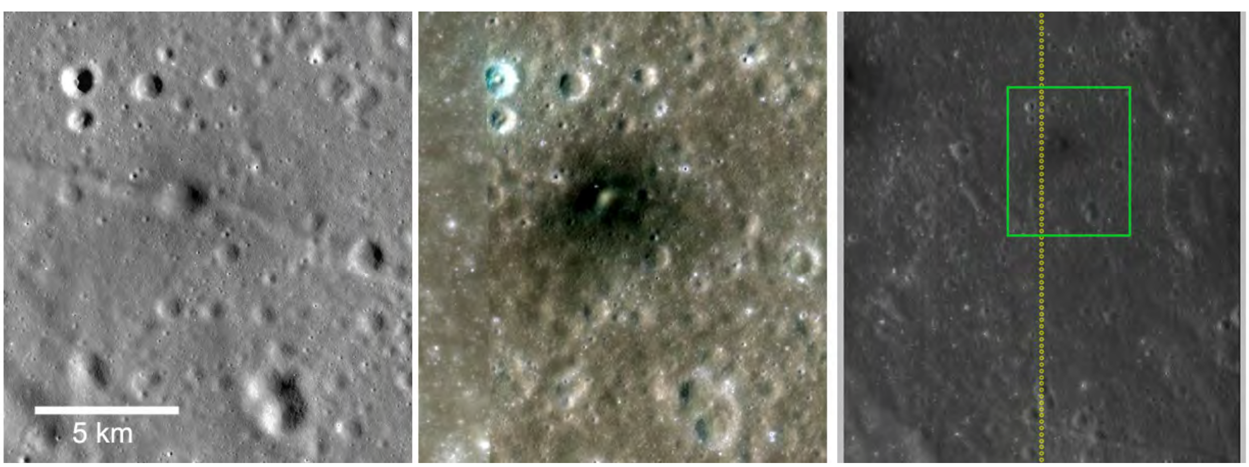
***Figure 1.** Kaguya SELENE views of the western floor of Alphonsus crater showing a small crater surrounded by dark, volcanic deposits (so called "Vent 8"). (Left) Terrain Camera (morning) mosaic; (Center) Multiband Imager "natural" color composite (bands 3, 2, 1 as R, G, B); (Right) Spectral Profiler (SP_2C_02_2693_S141_E3565) file showing 500-m observation footprints (yellow circles) superimposed on MI scene. The green outline shows the coverage of the TC and MI views.*



A History of the NASA Planetary Data System (PDS) Imaging Node's Map-A-Planet Legacy Web Services.
P. A. Garcia[1], C. E. Isbell[2], and L. R. Gaddis[3], [1]U. S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, Arizona 86001, pgarcia@usgs.gov.

Introduction: The PDS Map-A-Planet web service [1-3] was originally developed in the late 1990s in response to the increased demand for access to planetary images and other data. This demand was facilitated by the rapid rise in popularity of then-new public access to the internet. At that time, the boom in internet technology had begun to enable easy access to the large amounts of data collected by NASA's Space Exploration Programs. These data had previously been unavailable in readily usable form to most people, including educators, citizens, and even scientific researchers.

Initially, Map-A-Planet only served data for Mars and the Earth's Moon, but as it grew in popularity, more data sets, as well as advanced processing capabilities, were added to the system. Today, the system serves scientifically accurate planetary global mosaics, allowing users to create image maps from forty-six different image-based data sets. Users can visually navigate any of the available data sets, select various image density stretches and map projections, customize a geographic area selection, define the spatial resolution, and add graticules (latitude and longitude grids) to their maps. In addition to real-time navigation, the order system allows users to order their maps in a variety of file formats. Twelve lunar elemental abundance tabular data sets are also available via Map-A-Planet.

Map-A-Planet users can be found in various parts of the world, and a number of college and university professors have incorporated Map-A-Planet into their class curricula. Map-A-Planet is freely available to the public and is used not only by educators, but also many lay persons and research scientists as well.

Planetary Bodies for which data are available: Map-A-Planet began by serving only a very limited number of data sets, but grew to provide access to a wide variety of scientifically important data. The system uses image processing software and tiled Mosaicked Digital Image Map (MDIM) data to create cartographic image maps of users' desired targets and regions [4-12]. Planetary bodies now supported by MAP are Mars, Venus, Mercury, the Earth's Moon, four Galilean satellites (Callisto, Europa, Ganymede, Io), and five moons of Saturn (Rhea, Dione, Tethys, Iapetus, Enceladus).

Generating the Maps: In the early days of Map-A-Planet, software called *MapMaker* was developed and utilized to generate the image maps. For data sets which were tiled, and at that time distributed on multiple CDs, MapMaker was able to locate and load the tiles required to produce a particular map, scale the tiles to the desired resolution, knit the tiles together, and then apply the appropriate image stretch and map projection to finalize the product requested.

Later, Map-A-Planet was updated to incorporate the use of the USGS Astrogeology Science Center's signature Integrated Software for Imagers and Spectrometers (ISIS) [13-16]. The transition to using the ISIS software provided users with even more speed and flexibility in generating their map products and also provided capability for creating larger maps through the order system.

Advanced Capabilities and Data Products: *Order Formats and Options.* Over the years, capabilities were added to the Map-A-Planet system, typically by user request. Now, in addition to JPEG, TIFF, and GIF image formats, Map-A-Planet gives users the ability to order maps in 8-bit, 16-bit LSB, or 32-bit LSW, for PDS, ISIS and RAW formats. Users can choose between Bilinear Interpolation and Nearest Neighbor methods for data resampling. They can generate products in Sinusoidal, Simple Cylindrical, and Mercator map projections and can obtain products in Polar Stereographic projection through the order system.

Derived and User-Defined Data Products. One of the last (but popular) features to be added to the Map-A-Planet system was the use of predefined and custom mathematical functions. Users can now apply six predefined functions, as well as virtually unlimited custom arithmetic operations, to their data. Selected elemental abundance (including three FeO wt% [18-20] derivations and TiO2 wt% [18]) and two optical maturity (OMAT [20,21]) functions are available for selection when ordering Clementine UVVIS multi-band products. The user-defined arithmetic operation function, available through the order system, allows users to enter custom mathematical expressions and operators to be applied to any available data set. Examples of such applications include single-band operations (additive and multiplicative corrections such as radiometric calibration) and multi-band operations such as differences, ratios, and advanced data manipulation such as spectral curvature, band depths, and band tilt maps [22].

Latest Data. Among the last data sets to be added to the Map-A-Planet system were the Clementine Near Infra-Red 6-Band Mosaic [24], Lunar Orbiter Mosaic (USGS) [17], Lunar Prospector Elemental Abundances

[23], Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) Albedo and Thermal Inertia maps [25], Mars Orbiter Camera (MOC) Wide Angle Mosaic [26], and Mars Orbiter Laser Altimeter (MOLA) maps [27], MESSENGER MDIS/Mariner 10 Global Image Mosaic of Mercury [28] and Kaguya Laser Altimeter Topographic Map [29].

The Next Generation: Map-A-Planet has inspired other web-based cartographic services. Most recently, a new development team has produced "Map-A-Planet 2" (MAP2) which is now in beta release [30-31]. The current version of Map-A-Planet is scheduled to be decommissioned within the next year, when comparable services are available through MAP2.

Summary: The popular Map-A-Planet Cartographic Web Service was designed for a wide variety of users and intended to be available to everyone. For more than fifteen years, the system has made access to large, complex digital image map data sets considerably easier. Map-A-Planet development was responsive to the needs of planetary researchers, educators, and the general public, filling a niche not addressed by other services. The Map-A-Planet service is planned to be decommissioned in the near future, but will be survived by other web services leveraged off of Map-A-Planet features and design.

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OPUS: Now with Enhanced Geometric Metadata for Cassini Optical Remote Sensing Instruments. M. K. Gordon[1], M. R. Showalter[2], L. Ballard[2], N. Heather[2], [1]Carl Sagan Center, SETI Institute, Mountain View, CA (mgordon@seti.org), [2]Carl Sagan Center, SETI Institute, Mountain View, CA.

Introduction: The PDS Rings Node recently released a completely revamped user interface for our search tool, the Outer Planets Unified Search (OPUS). It is faster and enables even more powerful search capabilities than the previous version. Although OPUS is a Rings Node tool, it supports all of the data in a dataset, not just the ring observations.

Feature of Note: Enhanced Metadata. We have developed and incorporated into OPUS, detailed geometric metadata about Saturn and its rings and satellites. OPUS now supports with enhanced metadata Cassini ISS, VIMS, and UVIS data sets. CIRS data sets will be supported later this year. Geometric metadata is generated for each Cassini quarterly delivery and is based on the most current SPICE kernels available.

This extensive set of geometric metadata is unique to the Rings Node and enables search constraints such as latitudes and longitudes (Saturn, Titan, icy satellites, and rings), viewing and illumination geometry (phase, incidence and emission angles), ring open angles (to observer and to the sun), and distances and resolution. Unique parameters include the effective ring radial resolution − the radial resolution in km/pixel as projected onto the ring plane. This distinction is important because the rings can be highly foreshortened, in which case the actual resolution in the ring plane is much coarser than the standard resolution would indicate. Analogous information about the effective, foreshortened resolution on planetary surfaces is also provided. We also provide metadata to support an additional coordinate frame used to describe the geometry of nearly edge-on views of the rings. The database also includes identification of all rings and bodies in the field of view of each observation, not just the intended target.

Feature of Note: Support for HST planetary Observations. OPUS currently supports observations made using one of three Hubble Space Telescope (HST) instruments: ACS, WPC3, and WFPC2. We regularly access the archive of the HST, the “Mikulski Archive for Space Telescopes” (MAST), identify the planetary observations made by the HST instruments we support, and extract metadata and support files for each of those observations. We then generate PDS data volumes organized by observing proposal. These are entered into the OPUS database. These are nearly complete datasets, including browse products, but interestingly, not the actual data. MAST provides on-the-fly calibrated versions of their data, so we provide the relevant information necessary to obtain the calibrated data product from MAST. The key here is that for the supported instruments, planetary scientists can now search the HST archive using a search tool designed for planetary data.

We are currently developing a new pipeline in order to add the STIS instrument to the list of supported HST instruments. Through a recently awarded external grant, over the next three years we will expand our MAST interface in order to add support for all HST instruments including the generation of enhanced geometric metadata for every product.

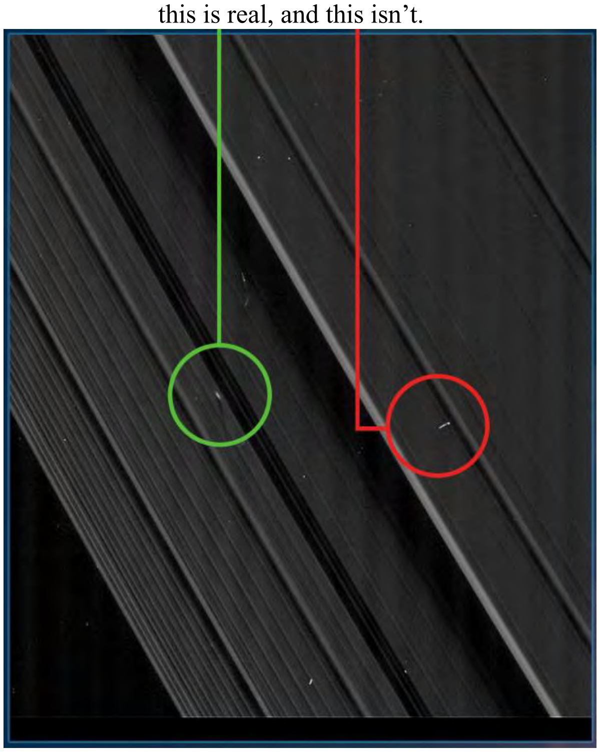
OPUS: http://tools.pds-rings.seti.org/opus/
Rings Node: http://pds-rings.seti.org/

PDS and NASA Tournament Laboratory Engaging Developers: The Rings Challenge. M. K. Gordon[1], M.R. Showalter[2], J. Odess[3], A. Del Villar[3], A. LaMora[3], J. Paik[4], K. Lakhani[4],R. Sergeev[4], K. Erickson[5], C. Galica[6], E. Grayzeck[7], T. Morgan[7], W. Knopf [5], [1]Carl Sagan Center, SETI Institute, Mountain View, CA (mgordon@seti.org), [2]Carl Sagan Center, SETI Institute, Mountain View, CA (mshowalter@seti.org), [3] Appirio Inc, Powered by Topcoder, [4] Crowd Innovation Lab/NASA Tournament Lab at Harvard University, [5] NASA Headquarters, [6] NASA Tournament Lab, [7]NASA Goddard Space Flight Center.

Introduction: The Planetary Data System (PDS), working with the NASA Tournament Lab (NTL), Crowd Innovation Lab at Harvard University, and the Topcoder community at Appirio, Inc, is using challenge-based competition to generate new applications that increase both access to planetary data and discoverability—allowing users to "mine" data, and thus, to make new discoveries from data already "on the ground".

The Rings Challenge is one such set of competitions employing crowd sourcing and machine learning to develop a set of algorithms to identify persistent, non-axisymmetric features in the rings of Saturn.

THE RINGS CHALLENGE
Teach a computer that
this is real, and this isn't.



How Hard Can It Be? Previously, Topcoder ran a similar contest: develop an algorithm to be used against Earth observation satellite images of Mongolia in an attempt to distinguish ancient from modern structure in order to identify the site of the grave of Genghis Khan, with promising results. There were three major differences between the contests. 1) The area of Mongolia is 604,246 square miles; the surface area of Saturn's rings is 44,710,000,000 square miles. 2) Landmarks in Mongolia (e.g., mountains, cities) do not change their relative locations; in the rings every particle is on its own orbit; everything changes, all the time. 3) For the Mongolia project, Topcoder was able to use approximately 10,000 annotated images as a base set for machine learning; for the rings challenge, the annotated base set contained about 800 images.

Organization of the Challenge: The Challenge was tackled by running a series of separate contests to solve individual tasks prior to the major machine learning challenge. Each contest was comprised of a set of requirements, a timeline, one or more prizes, and other incentives, and was posted by Appirio to the Topcoder Community. The Community is comprised of over 750,000 multinational software designers, developers, and data scientists. Community participation is free for members and the contests were unrestricted; no academic or experience qualifications were required. Contest solutions were selected from submissions according to objective score. In the case of the machine learning challenge (a "Marathon Challenge" on the Topcoder platform), members competed against each other by submitting solutions that are scored in real time and posted to a public leaderboard by a scoring algorithm developed by Appirio for this contest.

The Marathon Challenge resulted in four highly competitive, but less than satisfactory solutions. A subsequent contest was then run to refine the best solutions.

Participation in the Challenge: NASA and space related challenges elicit a strong response from the Topcoder community as they provide citizen scientists opportunities to contribute to space missions that are normally inaccessible to them.

Participation	
Total Prizes/Incentives	$47,637
Total Contests	11
Total Registrants	266
Countries Rep'd	40
Unique Solvers	22
Unique Winners:	8

Results: After more than a year of refining objectives, identifying constraints, and executing ten sequential contests, the final contest is underway. The refined winning algorithms will be run against the approximately 30,000 highest resolution images of the rings obtained by Cassini.

We will report on the details of the challenge and its contests, and the result of that final validation.

THE PLANETARY DATA SYSTEM NEW GEOMETRY METADATA MODEL. E. A. Guinness[1] and M. K. Gordon[2], [1] Dept. of Earth and Planetary Sciences, Washington University, St. Louis, MO (guinness@wustl.edu), Carl Sagan Center, SETI Institute, Mountain View, CA (mgordon@seti.org).

Introduction: The NASA Planetary Data System (PDS) has recently developed a new set of archiving standards based on a rigorously defined information model. The new standards are known as PDS4. An important part of the new PDS information model is the model for observational geometry metadata, which includes, for example, attributes of the lighting and viewing angles, position and velocity vectors of a spacecraft relative to Sun and to the observing body at the time of observation and the location and orientation of an observation projected onto the target.

Prior to PDS4 there were no standards on what geometry metadata to include in PDS labels. The result was that the data sets varied in the geometry information in labels from none to fully describing the geometry of an observation. The new PDS4 geometry model provides standardization in the definitions of the geometry attributes and provides consistency of geometry metadata across planetary science disciplines. This standardization will enhance the analysis and interpretation of observational data by the science community and will enable harvesting of the geometry information to support discipline level searches by users to discover data of interest to them.

Model Requirements: The PDS4 geometry metadata model is based on requirements gathered from the planetary research community, data producers, and software engineers who build search tools. Requirements are also based on a survey of geometry data contained in existing PDS data sets. An overall requirement for the model is that it fully support the breadth of PDS archives including a wide range of data types collected by instruments observing many types of solar system bodies such as planets, ring systems, moons, comets, and asteroids.

Specific geometry model requirements include: (1) Separate geometry classes are required to support different mission types, e.g., orbiters and flybys, landers and rovers, and Earth-based observations; (2) Geometry classes need to be flexible, require a minimum set of attributes, but define optional attributes to fit the wide range of planetary observations archived by the PDS; (3) References to source data, the methods used to compute geometry attributes, and relevant coordinate/reference systems need to be specified along with the geometry data; (4) The model needs to include footprints of observations projected onto a planet's surface that go beyond just the location of center or corner points; and (5) The PDS4 geometry model needs a method to handle updates to geometry data should instrument pointing or spacecraft position information improve.

Model Structure: The PDS4 geometry model is implemented in XML, as is the main PDS4 information model. Both models use XML schema for validation. The use of XML in PDS4 greatly enhances the ability to build a standardized structure for PDS labels in that parameters appear in a specified order and location in the label, and required and optional parameters are clearly indicated. XML also makes it easier to read the PDS labels using software that can parse an XML document, and label validation is straight forward by testing the label against the model schema.

The geometry model is structured such that there are several high-level components, each of which is focused on a specific class of missions. So far, the mission classes in the model include orbital/flyby and landed/rover missions. Future implementations of the model will include the case for observations made from earth-based telescopic instruments. The high-level components use lower-level classes that define fundamental objects such as generic vectors and quaternions. If a particular mission has a need for a set of specialized distances or vectors that are not included in the higher-level portion of the model for that mission class, then those specialized objects can be included by using the generic classes from the lower-level component to extend the higher level model.

The high-level model for orbital and flyby missions contains classes for specific distance and velocity vectors (e.g., spacecraft to target and target to sun), lighting and viewing angles, and the projected field-of-view onto the target for both an individual point (e.g., pixel in an image) or the full footprint of the observation (Fig. 1). The model requires a reference to the source data, time, and coordinate system used for generating the geometry parameters be included in the label. Geometry information can be provided for more than one body, such as a planet and one or more of its moon, in the same PDS label if multiple targets are observed.

The landed and rover mission high-level component includes classes to define the vehicle position and orientation. It contains classes to describe a camera model for image data. There are also classes that specify the position and orientation during an observation of a robotic arm and its tools (Fig. 2).

Status: An initial version of the PDS4 geometry model has been recently released as XML schema. This version is being reviewed by the PDS4 information model design team and by the International Planetary Data Alliance (IPDA) group. The XML schema for the geometry model, along with all other PDS4 XML schema can be obtained at http://pds.nasa.gov/pds/schema.

Acknowledgement: The PDS4 geometry working group includes E. Guinness and M. Gordon as co-chairs with members A. Raugh from U. of Maryland; C. Isbell from U.S. Geological Survey; and B. Semenov, C. Acton, E. Rye, and S. Hughes from the Jet Propulsion Laboratory.

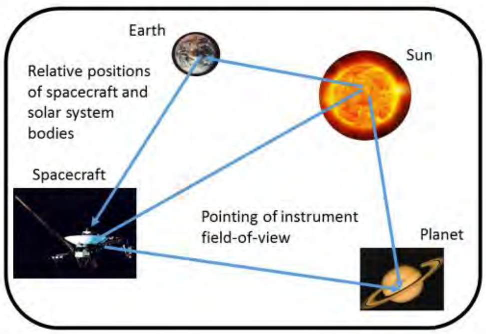


Figure 1: This diagram displays some characteristics of geometry for orbiter or flyby missions such as relative positions of the spacecraft and other solar system objects and the instrument position and field-of-view projected on the body being observed.

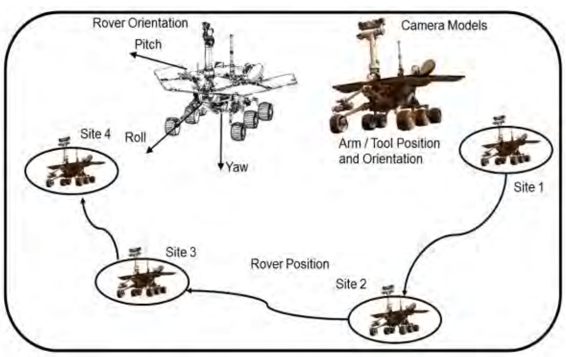


Figure 2: This diagram illustrates the components for a landed spacecraft geometry. The case for a rover is depicted. Rover geometry includes rover position and orientation, along with arm and tool position and orientation. Another important aspect is a camera model for each camera. The case for landers is similar except that the spacecraft position and orientation do not change with time.

J-ASTEROID, 3D DATA FORMATS AND ISSUES FOR THE VISUALIZATION OF SMALL BODIES.

W. Hagee[1], S. Anwar[1], D. Noss[1], S. Dickenshied[1], [1]Mars Space Flight Facility, 201 E Orange Mall, Arizona State University, Tempe, AZ 85287 USA.

Introduction: J-Asteroid is part of the JMARS (Java Mission-planning for Analysis and Remote Sensing) suite of Geographic Information System (GIS) applications developed by Mars Space Flight Facility at Arizona State University (ASU). J-Asteroid extends JMARS functionality as a mission planning and data analysis tool to asteroids and other small celestial bodies. Historically JMARS was created to be the mission planning tool for the THEMIS (THermal EMission Instrument System) instrument on board the Mars Odyssey Spacecraft. Since its release, JMARS mission planning and data analysis capabilities have been extensively enhanced to support many NASA missions including MRO, LRO, Dawn, and OSIRIS-REx. In addition to supporting NASA missions, JMARS is also used in ASU and NASA educational outreach programs and is available to the general public.

J-Asteroid was initially created to support the Dawn mission to Vesta and Ceres and is being extended further to provide both mission planning and data visualization capabilities for the OSIRIS-REx mission to Bennu. A key enhancement for the OSIRIS-REx mission is the ability to mission plan and visualize data in 3D. This 3D visualization capability, including the rendering of arbitrary data sets and user-created data onto complex shape models, has been extended to other small bodies including Itokawa and Eros.

Poster Contents: This poster will describe some of the many data formats that have been created to support 3D visualization. The pros and cons of each format in terms of size, tool support, performance, and suitability for small bodies will be presented. Issues that have been encountered fusing different data formats including projected data will also be presented.

One of the most interesting issues of visualizing small body data in 3D or in a projected map is the representation of multiple surface points along a single radius line or multiple surface solutions for a single Longitude/Latitude position. This issue is problematic for some data formats when rendered in 3D but not for others.

Examples will be shown to illustrate the key data format issues.

THE NASA REGIONAL PLANETARY IMAGE FACILITY NETWORK: A FIVE YEAR PLAN.

J. J. Hagerty, U.S.G.S. Astrogeology Science Center, Flagstaff, AZ 86001 email: jhagerty@usgs.gov.

Introduction: NASA's Regional Planetary Image Facilities (RPIFs) are planetary data and information centers located throughout the United States, in Canada, and overseas. The U.S. locations are funded by both NASA and their host institutions [1]. A network of these facilities was established in 1977 to "maintain photographic and digital data as well as mission documentation. Each facility's general holdings contain images and maps of planets and their satellites taken by Solar System exploration spacecraft. These planetary data facilities, which are open to the public, are primarily reference centers for browsing, studying, and selecting planetary data including images, maps, supporting documentation, and outreach materials. Experienced staff at each of the facilities can assist scientists, educators, students, media, and the public in ordering materials for their own use" [2].

Since it was formally established, the network of RPIFs has expanded to nine U.S. facilities and seven facilities in other countries. The first RPIF to be established outside of the U.S. was in the United Kingdom in 1980, at University College London (UCL), and since then RPIFs have been set up in Canada, France, Germany, Israel, Italy, and Japan. Through its longevity and ability to adapt, the RPIF Network has leveraged its global reach to become a unique resource covering 60 years of international planetary science.

Historically the Network nodes have had an institutional focus, whereby they provided resources to local clients, and communicated with other nodes only when the need arose. Using this methodology, the nodes of the RPIF Network, hereafter referred to as RPIFN, have combined to serve an average of ~65,000 people per year since 2000. However, with the advent of simpler and more wide-ranging forms of data transfer and sharing, it is clear that the nodes can operate together to provide the planetary science community and the public with greater access to: 1) archived mission products (e.g., maps, photographs, films, and documents); 2) mission-enabling documentation (e.g., data on previous mission design, development, implementation, and evaluation); 3) science and public research support, and 4) outreach experience and capabilities. Each node of the Network has unique capabilities that meet one or more of the above criteria; however, by linking the nodes through a centralized website and database, it is now possible to provide a wider array of materials to a wider array of users.

Distribution of Planetary Geologic Maps: Each node of the RPIFN maintains a mixture of common and unique collections. The Regional Planetary Information Facility at the USGS Astrogeology Science Center is unique in that one of its primary functions is to serve as a store house and distribution point for planetary geologic maps. At present, the USGS RPIF has 60,000 USGS lunar and planetary maps and now has a full inventory of all maps in the collection.

The USGS RPIF is responsible for distributing (free of charge) newly published I-maps to the other nodes of the RPIFN, as well as to interested members of the planetary science community. In recent years it became clear that the distribution process was outdated and inefficient. Given this motivation, the USGS RPIF has been working with leaders in the planetary mapping community to increase the efficiency of the distribution process and to raise awareness of the importance of planetary geologic maps. One of our major continuing efforts is to meet with members of the community at the Annual Planetary Geologic Mappers meeting to discuss the importance and distribution of planetary geologic maps. As a result of these efforts we have established a web-based distribution point (Fig. 1) that is accessible to users who are sent an invitation email with a link to the distribution page.

Figure 1. New online order form for the USGS Planetary Map collection.

Five Year Plan: The role of the RPIF Network is evolving as key historical planetary data sets are converted to digital files and are made available online. Instead of trying to compete with vast array of materials housed in digital servers (i.e., the PDS, whose goal is to focus on serving more technically oriented NASA-funded users), *the RPIF Network will serve as a valuable resource for specialized knowledge and services that will make it possible to remove the barriers associated with locating, accessing, and using planetary science data, particularly derived data products. The goal of the Network is to provide support to a broad audience of planetary data users.*

The RPIF Network nodes will continue to serve as reference centers that are needed for preserving and accessing derived products from Solar System exploration missions, and will continue to do so for future missions as well. In an effort to meet our customer's needs, we aim to achieve the following primary goals:

1. Maintain and improve the foundation that has been established over the past four decades so as not to lose critical, historical information. This goal will be aided by a systematic effort to scan and digitize fragile materials as a means of increasing access and preserving the materials.
2. Help users to locate, access, visualize, and use planetary science data. In an effort to make this possible, RPIF personnel are being trained in the use of common planetary data sets and processing tools such that they can assist novice researchers with locating and using planetary data. One tool that will be used in this effort is the Magic Planet from Global Imagination (Fig. 2). Each US facility of the Network now has one of these globes which will make it easier for researchers to visualize and work with global data sets.
3. Improve the connection between the Network nodes while also leveraging the unique resources of each node. To achieve this goal, each facility will develop and share searchable databases of their entire collections.
4. Promote the Network in an effort to make potential users aware of resources and services provided by the Network.

By achieving these goals, we will introduce new users to data products from past, current, and new missions. The underlying premise of data needs for users of the RPIF Network (whether hard copy or digital) is that research and discovery does not end with each mission, but continues for generations to come. As such, the RPIF Network provides the bridge between generations as one phase of exploration ends and another begins.

In summary, over the next five years the RPIF Network will continue its traditional service as a source of derived data products and expand its reach through new technologies by making obscure, but critical data sets available to a wider user community. New initiatives in digitizing hard copy data will make valuable resources widely available and provide a mechanism for long term preservation. It should be noted that digitization of all photographic imaging data at the same resolution as the original, cannot be fully achieved except at large cost; therefore, access to hard copy materials remains necessary. Consequently, the distributed reference collections held by the RPIFs remain an important and accessible resource. By leveraging the expertise and resources of the RPIF Network, NASA will be able to make the exciting new discoveries of planetary science more widely available, which will allow the Network to better serve NASA, the planetary science community, and the general public.

For more information, or to request materials, please contact any of the RPIFs listed below. Additional, detailed information can also be found at http://www.lpi.usra.edu/library/RPIF

Acknowledgements: The U.S. nodes of the RPIF Network are supported by NASA as well as by leveraging funds from host institutions.

References: [1] Shirley and Fairbridge, eds. (1997) *Encyclopedia of Planetary Sciences*, Chapman and Hall, London, 686; [2] Muller and Grindrod (2010) *European Planetary Science Congress 2010*, 883;

Figure 2. Magic Planet from Global Imagination. A new visualization tool for global planetary data.

Deploying a Planetary Data Tool Registry

S. Hardman, J.S. Hughes, R. Joyner, D. Crichton, E. Law
Jet Propulsion Laboratory, California Institute of Technology

During the 2012 Planetary Data Workshop, there was a call from workshop participants for the International Planetary Data Alliance (IPDA) to offer and maintain a registry of tools and services relating to the access and use of planetary data. The registry [1], considered a prototype, was developed and deployed to the IPDA web site and populated by the IPDA member agencies. The Planetary Data System (PDS) [2] is looking to upgrade this registry by increasing its visibility and enhancing its functionality along with incorporating the registered tools into PDS data search results. This presentation will describe the work towards the development and population of this registry for the planetary data user community.

References:

[1] http://planetarydata.org/documents/services/registry/
[2] http://pds.nasa.gov/

PLANETARY GIS AT THE U.S. GEOLOGICAL SURVEY ASTROGEOLOGY SCIENCE CENTER.

T.M. Hare, J.A. Skinner, Jr., C.M. Fortezzo, L.R. Gaddis, U. S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ, 86001 (thare@usgs.gov).

Introduction: For the past 51 years, the USGS Astrogeology Science Center (ASC) has been a resource for the integration of planetary geoscience, cartography, and remote sensing. In more recent years, the USGS ASC has supported Geographic Information Systems (GIS) for planetary data integration, geologic mapping and spatial analysis. This abstract is provides a brief overview of current GIS initiatives and related online services at ASC.

Background: One of the major roles of the USGS ASC is to support NASA missions and research programs through software focused on cartographic data processing. In particular, the Integrated Software for Imagers and Spectrometers (ISIS) [1] software is a specialized image processing package for working with planetary image data from NASA spacecraft missions such as Voyager, Viking, Galileo, Mars Global Surveyor, Mars Express, Cassini, Lunar and Mars Reconnaissance Orbiters and MESSENGER. While the products made with ISIS are science-ready cartographic products, the software was not designed for detailed geologic analysis or geomorphologic mapping and robust spatial analysis. Thus, most researchers must take these generated products into a remote sensing or GIS application for further analysis.

GIS Support: The USGS ASC, mostly through the Mapping, Remote-sensing, Cartography, Technology, and Research (MRCTR, pronounced "Mercator") GIS Lab, supports several GIS initiatives including training, tutorials, and plug-ins for Esri's ArcMap GIS and other open-source desktop GIS applications like QGIS. The MRCTR GIS Lab also provides code development for the Geospatial Data Abstraction Library (GDAL) to support planetary image formats and specialized planetary functions for online map viewers like Openlayers and ArcGIS Online. Lastly, MRCTR supports standards for metadata, map projection registries and real-time mapping servers like Web Mapping Services [2].

ArcMap GIS: While the USGS ASC does not solely endorse Esri's ArcMap GIS, we recommend it for geologic mapping and a number of spatial analysis tasks. Unique to ArcMap, Esri has worked directly with the Federal Geographic Data Consortium (FGDC) to provide support for USGS-required geologic symbology (e.g., geologic contacts and fault types) and metadata. This capability is critical to the USGS for producing publish-ready geologic maps whether for Earth or an extraterrestrial body. Working with the USGS ASC, Esri has also incorporated radius values (as recommended by the International Astronomical Union [IAU]) for nearly all planets in our Solar System and their moons within ArcMap and their forthcoming ArcGIS Pro desktop applications. As a result, ArcMap has direct map projection support for most products derived by the community [3, 4].

QGIS and GRASS GIS: QGIS, previously known as Quantum GIS, is a very capable open-source desktop GIS application. The latest release comes with built-in support for planetary map projections. In 2006, the USGS ASC and the Jet Propulsion Laboratory published a recommended coded set of planetary projections using the IAU2000 namespace [5]. Though these were made available from the projection registry site SpatialReference.org, they were not directly added to QGIS. Due to the efforts of the Lunar Reconnaissance Orbiter Camera Team at Arizona State University, these IAU2000 projection codes now ship with QGIS. Also, thanks to work by Alessandro Frigeri (currently at the Italian Institute for Space Astrophysics and Planetology), these radius definitions are also included within the GRASS environment [6].

GDAL: The Geospatial Data Abstraction Library (GDAL), released by the Open Source Geospatial Foundation (OSGeo), offers powerful capabilities for converting and processing planetary data. GDAL is a format translation library written in C++ for geospatial raster and vector data [7]. In 2007, the USGS ASC added support for the ISIS3 format within GDAL and updates to the ISIS2 reader and raw Planetary Data System (PDS) formats. In late 2014, VICAR support was added by Sebastian Walter, from the Freie Universität Berlin [8].

Any application that supports the GDAL library can now easily understand common planetary data formats, including the planet definition, projection parameters, and label information like pixel offset and multiplier. Popular applications with GDAL support include the applications noted above and many others, such as MapServer, Opticks, and Generic Mapping Tools. For applications that do not integrate GDAL, the bundled routines released with GDAL can be used to convert the ISIS and PDS formatted data into well-supported geospatial formats like GeoTIFF, GeoJPEG2000, ENVI, and many others. Lastly, GDAL's C++ code-base has been wrapped to support scripting languages like Python. Using these capabilities, the USGS ASC has created new tools for researchers, including simple image stretching and classification routines to spectral image viewers [9].

Infrastructure Services: Several behind-the-scenes online services and databases at USGS ASC provide essential GIS support for planetary data access and processing. The databases described below use the open-source PostgreSQL database and PostGIS extensions for added geospatial support.

UPC: The PDS Imaging Node's Unified Planetary Coordinates (UPC) database standardizes the numerous, disparate planetary orbital datasets into a single coordinate system [e.g., 10] and simplifies data identification and delivery for users. The UPC has two main parts: (1) a spatial database containing improved geometric and positional information about planetary image data that has been computed using a uniform coordinate system and projection onto a common planetary surface shape, (2) a process by which continual maintenance and updates of the database are performed. For GIS users, the image footprints are separated by body and instrument and can be obtained in a shapefile format.

Astropedia Data Portal and the PDS Imaging Node Annex: Astropedia is a secure, long-term access and storage repository for high-level planetary cartographic data products [11]. At the core of Astropedia are the ingestion methods, metadata parsing and cataloging, and the local data storage repository. Planned improvements to Astropedia include the addition of GIS catalog services [12]. The Annex (sponsored by the PDS Imaging Node) uses the Astropedia data portal to help planetary researchers archive and release derived geospatial products created from archived PDS data. Examples of products are cartographic and thematic maps of moons and planets, local and regional geologic and/or geomorphologic maps, topography of planetary landing sites, and tabular data. Many such products likely have been developed as a result of NASA data analysis programs, often years after active missions (and their accumulating archives) have ended.

Astrogeology Web Maps: Astrogeology Web Mapping Services (WMS) and Web Feature Services (WFS) are based on Open Geospatial Consortium standards and allow capable mapping clients to view full-resolution global and polar planetary basemaps and supporting geospatial databases. In short, a WMS service accepts queries for map-projected layers and returns requested data in a simple image format (e.g., JPEG, PNG). A WFS service returns geographical features representing data such as name, type, and the spatial geometries (point, line, or polygon) associated with the feature. Our services currently support more than 100 image layers and over 30 different planetary bodies [13]. For GIS users, these layers are also listed on Esri's ArcGIS Online data portal under the Planetary GIS group and can be directly accessed from ArcMap, QGIS or GDAL (bit.ly/PlantaryGIS).

POW and MAP2: The Map Projection on the Web (POW) [14] service allows users to convert raw PDS images to science-ready, map-projected products. Map-a-Planet 2 is a major update to the popular Map-a-Planet web site [15]. The service allows global image products to be re-projected, stretched, clipped, and converted into a variety of useful image formats. Both POW and MAP2 leverage the capabilities of Astropedia, ISIS, GDAL, and the USGS ASC processing cluster and web services.

OpenLayers Planetary Extensions: OpenLayers is a javascript library for displaying map data in web browsers. The USGS ASC developed and supports several OpenLayers 2.x extensions to properly display planetary bodies, including use of either planetocentric or planetographic latitudes, positive-east or -west longitudes, and correct scale bars [16].

Conclusion: The large variety of planetary data and services provided by Astrogeology has grown to meet the cartographic and scientific needs of planetary researchers and will continue to evolve with the needs of the community.

References: [1] Keszthelyi, L., et al., 2013, LPSC XLIV, abs #2546. [2] Hare, T.M., et al., (2012), LPSC XLIII, abs #2871. [3] Hare, T.M., et al, (2009), LPSC XL, abs #2538. [4] Nass, A., et al. (2010), Planetary Space Sci., doi:10.1016/j.pss.2010.08.022. [5] Hare, T.M., et al, (2006), LPSC XXXVII, abs #1931. [6] Frigeri, A., et al., (2011), Planetary and Space Science 59, p. 1265–1272. [7] Hare, T.M., (2010), LPSC XLI, abs #2728. [8] Gaddis, L.R., Hare, T., and Beyer, R., 2014, Summary and abstracts of the Planetary Data Workshop, June 2012: U.S. Geological Survey Open-File Report 2014–1056, 199 p., http://dx.doi.org/10.3133/ofr20141056. [9] Laura, J.R., et al, (2015), LPSC XLVI, abs #2208. [10] Akins, S.W., et al, (2009), LPSC 40, abs #2002. [11] Bailen, M.S., et al, (2013), LPSC 45, abstract #2246. [12] Hare, T.M., et al, (2015), LPSC XLVI, abs. #2476. [13] bit.ly/AstroWMS [14] Hare, T.M., et at., (2014), LPSC XLV, abs #2474. [15] Akins, S.W., et at., (2014), LPSC XLV, abs #2047. [16] http://pilot.wr.usgs.gov/index.php?view=downloads

PDS ANNEX: A PDS IMAGING NODE REPOSITORY FOR GEOSPATIAL PLANETARY RESEARCH PRODUCTS. T.M. Hare[1], L.R. Gaddis[1], M. Bailen[1], S.K. LaVoie[2], J. Padams[2]. [1]USGS Astrogeology Science Center, Flagstaff, AZ 86001, [2]Jet Propulsion Laboratory, Pasadena, CA. thare@usgs.gov.

Introduction: The Imaging Node (IMG) of the NASA Planetary Data System (PDS) archives and delivers digital image collections from planetary missions [e.g., 1]. Included among these collections are nearly 700 TB of digital image archives, ancillary data (calibration files and software, geometric data, etc.), software, tutorials and tools, and technical expertise to support users of this collection. The PDS Imaging Node Annex, or simply ***The Annex,*** is a new online facility to support scientists who use PDS image data to create derived geospatial products registered to a solid planetary body (***Figure 1***). Examples of derived products are cartographic and thematic maps of moons and planets, local and regional geologic feature maps, topographic and perspective views of planetary landing sites, and tabular data containing unit information derived from planetary data. Many of these products have been developed as a result of NASA data analysis programs, often years after active missions (and their accumulating archives) have ended.

Architecture: The Annex service is built on an online catalogue infrastructure at the USGS Astrogeology Science Center called Astropedia [2]. Astropedia was created to provide a method to catalogue and readily serve the decades of images, mosaics and other derived data products created by Astrogeology scientists and cartographers. Detailed metadata, including documentation, links to source data, and publications are included for each product served. Many of these products have been derived from PDS data collections and are in the form of cartographic maps, global digital image mosaics [3, 4], and Geographic Information System (GIS) projects and layers [5].

Goals: The Annex will provide (1) support resources for the planetary community to archive PDS-derived products and (2) fast, on-demand access to derived data products via a robust search interface. Each delivered product includes a minimum set of metadata that cross-references publications, ancillary data and other related products. Products in The Annex can be searched using multiple methods including target information, mission or instrument keywords, author(s) and organization, as well as descriptive information available from the metadata.

The Annex uses the metadata standard created and maintained by the U.S. Federal Geographic Data Committee (FGDC); modified slightly to support planetary data [6, 7]. The FGDC standards, combined with existing PDS3 standards [8], are utilized to develop updated image and file labels for next generation archive, PDS 4 products [9, 10]. Planetary data products such as published USGS maps and Lunar Mapping and Modeling Project (LMMP) results are already required to have associated FGDC records [11].

FGDC geospatial metadata, is documentation that describes the rationale, authorship, attribute descriptions, spatial reference, errors and other relevant information about a given set of data. The Annex, by using this metadata standard also allows us to support this service as a proper Open Geospatial Consortium (OGC) Catalogue Services for the Web (CSW). Methods defined by the OGC CSW standard will facilitate such outside access, so that users need not build new search tools or application layer interfaces (APIs, [12]). Also the CSW API doesn't impede existing methods already supported by the community (e.g., RESTful web services provided by the PDS Geoscience Node [13]) and is in use by many other nationally supported data portals e.g., Data.gov (http://data.gov).

Annex Requirements: The Annex accepts submission of geospatial products for archival that have a PDS planetary data heritage. Submitted products must have extensive metadata that meets PDS standards and using the joint PDS and FGDC planetary metadata standards. Data submissions and metadata development are initiated through a forms-based Web site that guides users through the process and specifies required data entries (see http://astrogeology.usgs.gov/pds/annex). Examples of required metadata are originator name and contact information, geographic coordinates, target body, descriptive caption, publication date, lineage and source information, validation and review status, quality and completeness assessments, linkages to other products, and literature citations. The information entered is converted to xml format for ingestion and retrieval through The Annex data catalog. These detailed metadata can readily be viewed for any product and serve to facilitate easy access through the existing Astropedia search interface.

Geospatial products submitted to The Annex are required to be validated and reviewed prior to publication. Products that have already been published in professional science journals will be considered peer-reviewed but PDS review is still required. Other products will require documentation of peer review by at least three researchers; IMG staff will assist with these reviews as needed. All data will be validated by PDS staff prior to public release in The Annex.

References: [1] Gaddis, L. et al., 2013, LPSC XLIV, abs. #2262; [2] Bailen, M. et al, 2012, LPSC XLIII, abs. #2478. [3] Eliason, E. et al., Mission to the Moon: The Clementine UVVIS Global Lunar Mosaic, 1999, PDS Volumes USA_NASA_PDS_CL_4001 through 4078, Produced by USGS and distributed by PDS. [4] Gaddis, L.R. et al., 2007, The Clementine NIR Global Lunar Mosaic, PDS Volumes USA_NASA_PDS_CL_5001 through 5078, produced by USGS and distributed by PDS. [5] Becker, T. et al., 2009, LPSC XXIX, abs. #2357. [6] Federal Geographic Data Committee, 2011, Preparing for International Metadata, Federal Geographic Data Committee, Washington, D.C., URL: http://www.fgdc.gov/. [7] Hare, T.M. et al., 2011, LPSC XXIX, abs. #2154. [8] PDS Standards Reference, v. 3.8, JPL D-7669, Part 2, URL: http://pds.nasa.gov/tools/standards-reference.shtml. [9] Crichton, D. et al., 2011, EPSC Abstracts, 6, abs. #1733. [10] Hughes, J.S. et al., 2009, LPSC XL, abs. #1139. [11] Law, E. et al., LPSC XLIV, abs. #1307. [12] Hare, T.M. et al., 2015, LPSC XLVI, abs. #2476. [13] Bennett, K.J. et al., 2014, LPSC XLV, abs. #1026.

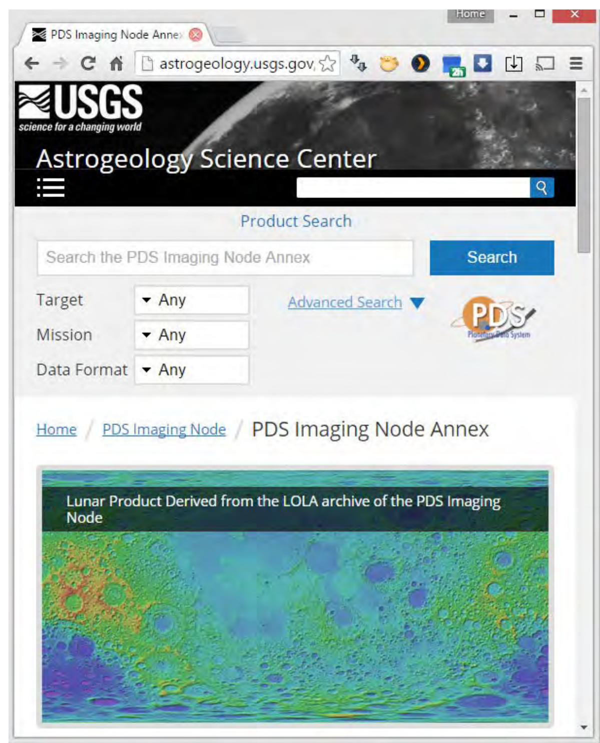
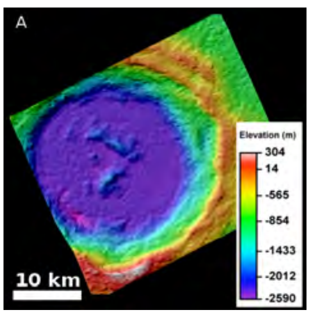


Figure 1. The Annex main interface showing the derived color shaded-relief for the PDS archived Lunar Orbiter Laser Altimeter (LOLA) digital elevation model from NASA's Lunar Reconnaissance Orbiter spacecraft.

HIGH RESOLUTION REGIONAL DIGITAL TERRAIN MODELS AND DERIVED PRODUCTS FROM MESSENGER MDIS NAC IMAGES. M. R. Henriksen[1], M. R. Manheim[1], K. J. Becker[2], E. Howington-Kraus[3], and M. S. Robinson[1]. [1]School of Earth and Space Exploration, Arizona State University, 1100 S Cady, Tempe AZ 85287 – (mhenriksen@ser.asu.edu), [2]Astrogeology Science Center, United States Geological Survey, 2255 N Gemini Dr., Flagstaff AZ 86001, [3]Retired

Introduction: One of the primary objectives of the Mercury Dual Imaging System (MDIS) is to acquire high-resolution images of key surface features [1]. Although (MDIS) was not designed as a stereo camera, stereo pairs are acquired from two orbits, with the camera pointing off-nadir for at least one orbit. This abstract describes the production of regional MDIS Narrow Angle Camera (NAC) Digital Terrain Models (DTMs) produced by the ASU and USGS teams, using a combination of the Integrated Software for Imagers and Spectrometers (ISIS) [2] and SOCET SET by BAE Systems [3].



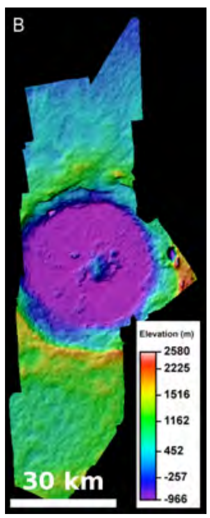


Figure 1: Color shaded relief of two completed MDI DTMs: A) Kertesz crater (27.36°N, 146.11°E) at 100 m/px. B) Sander crater (42.42°N, 154.64°E) at 150 m/px

Data Sources: The DTMs are extracted from NAC images and Mercury Laser Altimeter (MLA) tracks are used as a geodetic reference frame for the DTMs to improve accuracy [4]. Wide Angle Camera (WAC) images are used to bridge gaps in coverage or for control when no MLA tracks cover the NAC DTMs.

Mercury Dual Imaging System. The NAC is a 1.5° field-of-view (FOV) off-axis reflector, which is co-aligned with the WAC, a four element refractor with a 10.5° FOV. Each camera has an identical 1,024 x 1,024 charge couple device detector [1].

Mercury Laser Altimeter. Altimetry obtained from the Mercury Laser Altimeter (MLA) is used to increase the absolute accuracy of NAC DTMs. MLA is a time-of-flight altimeter that measures the shape of Mercury by using pulse detection and pulse edge timing to precisely determine the range from the spacecraft to the surface [4]. MLA data is only available only for latitudes between 90°N and 18°S due to MESSENGER's highly elliptical orbit, with periapsis at high northern latitudes. MLA measurements have a radial precision of < 1 m and a radial accuracy of < 20 m with respect to Mercury's center of mass [5].

Methodology: Stereo image selection is accomplished via a 2-step query of a MDIS image database that first identifies images with favorable illumination conditions (incidence, emission, and phase angles) and pixel scale, and then selects images which form acceptable stereo pairs, with good pixel scale ratios, parallax/height ratios, illumination compatibility, and image overlap [6]. Because of the highly elliptical orbit, NAC images used for DTM production range in resolution from 5 m to 50 m pixel scale. The amount of overlap and the actual footprint of the DTMs are affected by the topography and acquisition parameters such as center latitude, center longitude, and slew angles, with optimal convergence angle between 20° and 30°.

To produce DTMs of key regions of interest, ISIS is used to ingest images, to perform radiometric calibration, and to export the images (8-bit raw files and 16-bit TIFFs) in formats compatible with SOCET SET 5.6.0, along with associated spacecraft position and pointing information [2,3].

Images are then imported into SOCET SET, where all overlapping images are linked together with tie points and then bundle-adjusted. The NAC images are then manually controlled directly to shapefiles of the MLA tracks. If the sparsity of MLA points prevents direct control, WAC images are controlled to MLA instead. The NAC images are then tightly controlled to the WAC images in order to indirectly improve their geodetic accuracy.

Once a bundle adjustment solution has been achieved with an overall RMS of < 0.5 pixels and all residuals < 1.0 pixel, 16-bit TIFF images are imported and the solution information is transferred. The Next Generation Automatic Terrain Extraction (NGATE) program in SOCET SET is used to create a DTM at 3 times the pixel scale of the largest pixel scale image in a stereo pair, with typical ground sampling distances between 80 m and 150 m. After editing the DTM for artifacts, the final version is used to create 16-bit orthophotos in which distortion due to camera obliquity and terrain relief is removed.

Error Analysis: DTMs are subject to both qualitative and quantitative error analysis. Contour intervals created from the DTMs are compared to the images in stereo to confirm a close match with the terrain. The overlapping stereo pairs are also compared to the available MLA data to ensure that there is no tilt present in the DTM, and that the tracks closely align with the images in stereo. Quantitative metrics are also reported for precision and accuracy (Table 1).

Relative Linear Error. Precision is calculated by the SOCET SET Software as relative error at a 90% confidence level, meaning 90% of elevation measurements will be equal to or less than the reported value. Vertical precision is reported as relative linear error and is expected to be less than the ground sampling distance (GSD) of the DTM (~ 0.5 to 2.0 times the GSD of the images in the stereo pair) [3]. The horizontal precision of the DTM is reported to be equal to the GSD of the DTM, as the GSD is consistently greater than the circular error reported by SOCET SET.

Offsets from MLA. Positional accuracy is evaluated by comparing DTM elevations with MLA data. Wherever MLA tracks directly cross the DTM, the mean, median, and standard deviation of the offsets are evaluated (Fig. 2). However, due to the highly elliptical orbit of MESSENGER and the sparse MLA coverage, these calculations are not always possible. In this case, offsets are reported from the WAC DTMs used to control the NAC DTMs. Special care is taken to ensure that the difference in elevation between the NAC and WAC DTMs is <10 m, With the range accuracy of MLA better than 20 m, we would like the measured differences between the DTMs and MLA tracks to have similar values. However, as both our error analysis and DTM processing methods are still being refined, these levels of accuracy are currently challenging to obtain.

Table 1: Error Analysis for Completed Regions

	Sander	Catullus*	Kertesz*
Pixel Scale (m)	150	85	100
Mean Offset (m)	9.89	-313.9	157.9
Median Offset (m)	12.32	-306.1	151.9
Standard Deviation (m)	39.11	190.3	189.8
Vertical Precision (m)	101.3	83.7	99.74

* Values as compared to overlapping 1 km pixel scale WAC DTMs

PDS Products and Derived Products: In addition to the DTM in PDS IMG format, several derived products are provided. A confidence map and orthophotos of each image in the stereo pair are available at both the pixel scale of the DTM and at the largest native pixel scale from the stereo pair. A terrain shaded relief map, a color shaded relief map, a slope map, and corresponding legends are also provided at the pixel scale of the DTM in the EXTRAS directory of the PDS in GeoTIFF format, as well as a 32-bit GeoTIFF of the DTM. These derived GeoTIFF products were created using the Geospatial Data Abstraction Library (GDAL) [7].

Production and Future Work: Three sites consisting of ~40 stereo pairs are currently complete: Sander crater, Kertesz crater and the central peak of Catullus crater. The MESSENGER project plans to release over 60 stereo pairs in at least 6 regions as part of the MESSENGER DTM PDS Archive. Future work also involves including the higher resolution, higher precision DLR global DTM product to improve accuracy and resolve issues with sparse data at lower latitudes.

References: [1] Hawkin, S. E., et al. (2007) *Space Sci Rev, 131,* 247–338. [2] Anderson, J.A., et al. (2004) LPSC XXXV, Abstract #2039. [3] Burns, K. N., et al. (2012) *ISPRS XXII,* v. XXXIX-B4-483 [4] Cavanaugh, J. F., et al. (2007) *Space Sci Rev., 131,* 451. [5] Zuber, M. T., et al. (2012) *Science, 316,* 217. [6] Becker K. J. et al. (2015) *LPS XLVI,* Abstract #2703. [7] Warmerdam, F. (2008) *Open Source Approaches in Spatial Data Handling,* pp. 87-108.

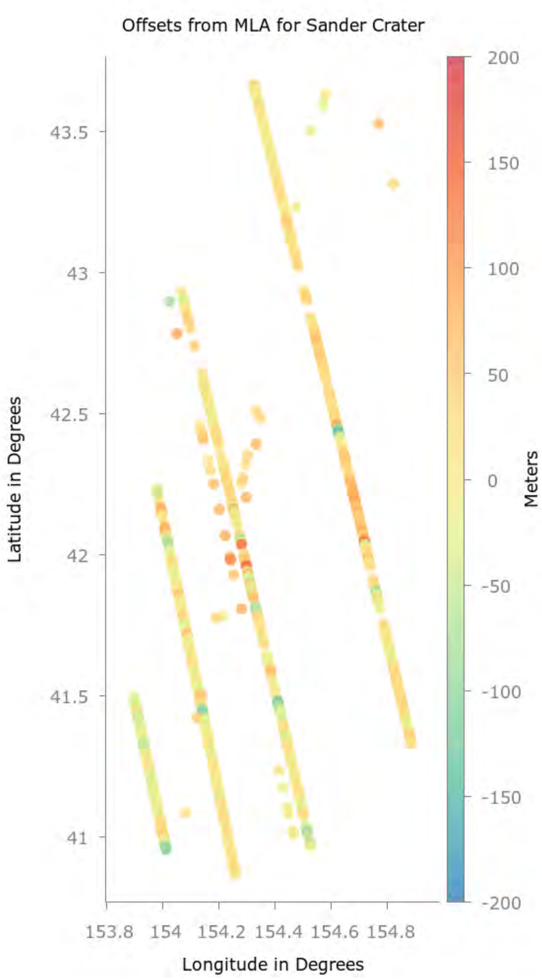


Figure 2: Plot showing the difference between MLA tracks and the Sander crater regional DTM (42.42°N, 154.64°E). This DTM mosaic consists of 36 stereo pairs and has a pixel scale of 150 m.

LROC NAC DTM PRODUCTION. M. R. Henriksen[1], M. R. Manheim[1], E. J. Speyerer[1], A.K. Boyd[1], and M. S. Robinson[1], [1]School of Earth and Space Exploration, Arizona State University, 1100 S. Cady, Tempe, AZ 85287 – (mhenriksen@ser.asu.edu)

Introduction: Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) stereo observations combined with Lunar Orbiter Laser Altimeter (LOLA) profiles are used to create dense and accurate DTMs of the lunar surface. The NACs consist of two linear pushbroom cameras designed to provide 0.5 meter pixel scale panchromatic images for a combined swath of 5 km at an altitude of 50 km [1]. Although the NACs were not designed as a stereo imaging system, it is possible to acquire stereo pairs by collecting images on two separate orbits, where the spacecraft is slewed off-nadir for at least one orbit. The convergence angle between the two images has a range of 10° to 40°. The amount of overlap and actual image footprints are affected by topography and acquisition parameters including center latitude, center longitude, and slew angle. LOLA is a pulse detection time-of-flight altimeter that was designed to measure the shape of the Moon by using precision orbit determination of LRO to precisely measuring the range from the spacecraft to the lunar surface [2]. By registering NAC DTMs to LOLA profiles, the absolute accuracy can be improved and evaluated. LOLA profiles with crossover correction and GRAIL gravity model improvement are accurate to within 10 meters horizontally and 1 m radially [3].

Methodology: DTM processing at ASU is completed using a combination of the Integrated Software for Imagers and Spectrometers and SOCET SET from BAE Systems [4].

Pre-processing. Image pre-processing is accomplished using ISIS to ingest, radiometrically calibrate, and remove echo effects [5] for all the images in a stereo pair or stereo mosaic. Orientation parameters stored in a series of binary and text based Spacecraft, Planet, Instrument, C-Matrix and Events (SPICE) kernels are applied to the images, which are then formatted for compatibility and imported into SOCET SET [6].

Relative Orientation. In order to register the images to the geodetically accurate LOLA grid [3], each image is first be corrected for relative orientation to the other images in the stereo model [7]. First, a set of “tie” points is inserted by matching pixels between images. A bundle adjustment is then performed to align the images using a multi-sensor triangulation (MST) algorithm [8,9]. Once an acceptable RMS error (< 0.5 pixels) is reached for the stereo model, a first-iteration DTM is extracted for absolute registration.

Absolute Orientation. Before April 2013, the standard registration technique (NAC DTM to LOLA profiles) was a manual optimization requiring the analyst to iteratively refine parameters to match two LOLA profiles to the DTM. The LROC team has since developed an automated tool using the Optimization Toolbox within MATLAB [10]. This program eliminates the need for manual parameter adjustments and can register multiple LOLA profiles simultaneously. Coordinates acquired by the MATLAB routines are exported back in to SOCET SET as control points, and a final bundle adjustment is performed to improve the absolute positioning of the NAC images. In addition to assessing overall RMS error and point residuals, the solution is evaluated on the latitude, longitude, and elevation RMS error values associated with the control points, which are considered acceptable within the known accuracies of the LOLA tracks.

Terrain Extraction. The Next Generation Automatic Terrain Extraction (NGATE) program in SOCET SET is used to extract DTMs from the epipolar rectified images [7,9]. NGATE uses image correlation and edge matching algorithms on each image pixel with a window size that adjusts with elevation differences to improve image correlation in a total of seven passes to create a dense model [10,11]. The DTM is then resampled to at least three times the ground sampling distance (GSD) of the images in order to reduce noise, typically at 2 or 5 m/px. Next, the DTM is run through a single pass of the Adaptive Automatic Terrain Extraction (ATE) SOCET SET application, smoothing elevation data by performing image correlation in a single pass on individual posts rather than at each image pixel, increasing the signal to noise ratio [12].

Orthophoto Generation. Once the DTM is processed, it is used to create orthophotos, or orthorectified maps of the parent NAC stereo images. The orthorectification process removes distortion due to camera obliquity and terrain relief, allowing accurate distance measurements to be made from the images maps [13]. Orthophotos are generated at both the native image resolution and at the resolution of the DTM for each image in the stereo pair.

Post-processing. For each set of stereo images, SOCET SET outputs the final DTM and Figure of Merit (FOM), or confidence map, as raw image files, and the orthorectified images as 16-bit GeoTIFFs (eight per stereo pair). These are imported into ISIS, mosaicked together, and converted to the standard PDS format for release. In addition, the Geospatial

Data Abstraction Library (GDAL) is used to derive a terrain-shaded relief map, a color-shaded relief map, and a color slope map from the DTM as 8-bit GeoTIFFs [14].

Error Analysis: Qualitative and quantitative error analysis is performed for every NAC DTM and both the relative and absolute accuracies are reported.

Relative. The relative linear error as calculated by SOCET SET is recorded for each DTM as a measure of precision. This value measures the one-dimensional error for elevation of one point with respect to another point, defined by the normal distribution function at 90% probability [9,11]. Precision is expected to be less than the DTM's GSD. The DTM horizontal precision is the same as the spatial sampling of the DTM [9].

Absolute. Every completed NAC DTM is compared to LOLA tracks, and the root mean square error (RMSE) for the offset is recorded. In addition, the final DTM is re-registered to the LOLA tracks and the offsets for latitude, longitude, and elevation recorded. To be considered accurate, the RMSE must be less than the pixel scale of the DTM and the offsets in latitude, longitude, and elevation need to be within the uncertainties attributed to the LOLA data, allowing for the precision of the DTM (for DTMs registered after April 2013, offsets should be < 10 m in latitude/longitude and 1 m in elevation). DTMs created prior to 2013 use an alternative registration technique, which was not as accurate; as a result, these DTMs may have systematic errors affecting the accuracy that are larger than LOLA uncertainties.

Jitter. Small spacecraft motions, or jitter, can emerge in the DTM as undulating geometric noise parallel to the image line. Extensive analysis of NAC images was conducted in an effort to pinpoint unknown sources of jitter and to identify affected images, but small levels of jitter may still be present in some NAC DTMs [15].

Scientific Applications: As the highest resolution topographic resource of the lunar surface available, the NAC DTMs serve as a valuable tool for the scientific and space exploration communities. Recent applications of NAC DTMs include the optimization of traverse planning using slope maps derived from DTMs [16], the calculation of melt volume estimates [17], and using Chebyshev polynomial fitting to characterize the morphology and age of small craters [18].

Production and Future Work: To date, ASU has processed 293 individual stereo pairs covering144 regions of scientific interest, covering a total area of ~97,138 km^2. The absolute accuracy has improved significantly. Changes to production, especially to registration, have reduced the overall time and expertise required to process a single stereo pair, allowing the ASU DTM production team to produce a higher volume of stereo mosaics and to reprocess many older DTMs to improve absolute accuracy. ASU DTMs and all associated products are released through the PDS and are available at http://wms.lroc.asu.edu/lroc/rdr_product_select.

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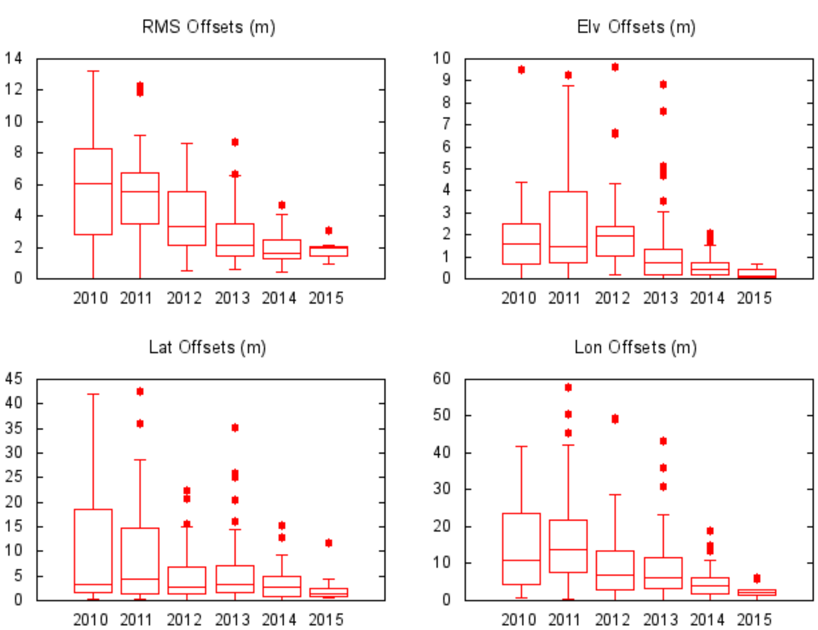

Figure 1: **Offsets between NAC DTMs and LOLA profiles (in meters) by year.** Errors are shown compared to most recent LOLA data (accuracy <10 m horizontally and < 1 m vertically). NAC DTMs are made at either a 2m or a 5m resolution. RMS errors are expected to be less than the resolution and Offsets are expected to be less than the accuracy of the available LOLA data, allowing for vertical and horizontal precision.

REGIONAL LROC NAC CONTROLLED MOSAICS AND ABSOLUTE ACCURACY ASSESEMENT.
M. R. Henriksen[1], D. Gojic[1], P. E. Gray[1], R. V. Wagner[1], M. S. Robinson[1], and the LROC Team[1] [1]School of Earth and Space Exploration, Arizona State University, 1100 S. Cady, Tempe, AZ 85287 – (mhenriksen@ser.asu.edu)

Introduction: High-resolution (0.5 – 2 m pixel scale) Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) [1] images of key features have been bundle-adjusted and mosaicked to provide seamless and geodetically accurate data sources for a variety of science and engineering studies [2]. These mosaics are typically composed of 2-10 NAC image pairs, specifically targeted on sequential orbits to have similar illumination. To ensure overlapping coverage, the images toward the outside of the targeted, or featured, mosaics can be slewed up to 30°.

As well as providing crucial scientific data, regional NAC controlled mosaics can also be used to assess the effectiveness of a bundle adjustment in improving NAC images' positional accuracy. A review of the literature on planetary controlled mosaics concludes that this is an error assessment that is has not been performed. NAC images' positional accuracy is well-characterized and highly precise due to the presence of retroreflectors and other human hardware on the Moon, as well as a highly accurate global geodetic Lunar Orbiter Laser Altimeter (LOLA) dataset with Gravity Recovery And Interior Laboratory (GRAIL) improvements to refine pointing parameters [3]. In addition, NAC regional mosaics are much smaller than the typical controlled mosaic. This makes them efficient, both in terms of resources and time, to use for testing the effects of various ground sources, radius sources, and bundle adjustment parameters on the positional accuracy of the resulting controlled mosaics.

Orientation parameters for each NAC image are described in a series of binary- and text-based Spacecraft, Planet, Instrument, C-Matrix and Events (SPICE) kernels [4]. LOLA smithed, or reconstructed, Spacecraft Position Kernels (SPKs) with GRAIL gravity model improvements [5] are available for NAC images acquired before June 20, 2014, providing location data that is accurate to within 20 meters [4]. Theoretically, then**,** a regional mosiac's positional accuracy could be improved by slightly adjusting image locations while simultaneously eliminating visible seams. Existing work shows that unless *apriori* point sigmas and bundle adjustment parameters are very tightly constrained, the control network bundle adjustment solutions displace images by larger distances than pointing uncertainties would suggest necessary, while decreasing overall accuracy with measured offsets up to 40 m [2].

Control Network Development: To mitigate any errors in the resulting controlled mosaics, control networks, consisting of tie points between overlapping images, ground points between the images and a 'ground truth,' and the associated point *apriori* sigma values, are carefully constructed. In addition to the images in the targeted featured mosaic, additional nadir-pointing, like-illumination images taken prior to June 20, 2014, and therefore having highly accurate spacecraft position and pointing, are included in the control network so that each ground point and tie point includes as many measures as possible (Table 1).

Table 1: Control Network Summary

Images	Points	Measures	Ground Points
32	9114	25383	120

Ground and radius sources are also selected to maximize accuracy. Ideally, highly controlled NAC digital terrain models (DTMs) and the DTM-derived orthophotos, or other highly accurate ground and radius sources, would be used exclusively for control. However, complete DTM coverage of a featured mosaic region is rarely possible due to the limited number of stereo observations. Therefore, ground sources are typically constructed by layering map-projected nadir pointing images with smithed SPKs underneath any available NAC DTM [6] orthophotos of the region to provide full ground coverage for the mosaic. If there is no coverage by a NAC DTM radius source for a particular ground point, the radius for that point defaults to the GLD100 [7].

Apriori sigma values are assigned to each ground point based on the known accuracies of the ground and radius sources. When a DTM orthophoto is available, estimated latitude and longitude errors are used as the horizontal values. If only a map-projected image is available, an uncertainty of 15 m is used instead. The *apriori* radius value is assigned three times the root mean square (RMS) error of the offset between the NAC DTM and LOLA tracks. If a point uses the GLD100 as a radius source, an *apriori* sigma value of 40 m is used, based on the GLD100's reported uncertainty [7].

The control network is bundle-adjusted using the Integrated Software for Imagers and Spectrometers (ISIS) application *jigsaw* [8,9]. While a solution with smaller residuals and better convergence (indicated by the *Sigma0* output [2,9]) can be achieved by solving over the existing pointing polynomials and by solving for position, velocity, and acceleration for both spacecraft position and camera pointing, we have found that the mosaic is more accurate when solving for only a few parameters. Therefore, spacecraft position, camera angles and camera velocities are the only positioning and pointing options typically used for our solutions. Additional parameters (*overhermite* and *overexisting*) that utilize the current camera pointing and spacecraft position as *apriori* values are included as well, as these have been found to slightly improve both the overall bundle adjustment solution *Sigma0* value and the absolute accuracy (Table 2).

Error Analysis: In addition to analyzing the output from the bundle adjustment solution, the estimated absolute accuracy of the ground coordinates is assessed. An automated version of the method described in [10] is used to calculate the true ground coordinate. Selected ground coordinates from a completed, map-projected mosaic are input, and the pixels at those ground coordinates are matched to line and sample values in overlapping NAC images with smithed SPKs (accuracy of +/- 20 m). The ground coordinates are then averaged to provide a single 'ground truth' coordinate to compare to the controlled mosaic [10]. We would therefore expect the corresponding point in a mosaic with an accurate bundle adjustment to be within 20 m of this 'ground truth' coordinate.

Controlled Mosaics of Apollo 17 Landing Site. Apollo landing sites make good test candidates for confirming the accuracy of NAC controlled mosaics because the locations of the anthropogenic objects (lunar module (LM), Lunar Roving Vehicles (LRV), and retroreflectors) are both well characterized [10] and identifiable in the mosaics. Furthermore, high-resolution NAC DTMs are available for all the landing sites. Several versions of the Apollo 17 landing site controlled mosaic (3 NAC pairs) were made in order to characterize the effects of varying solve parameters and radius sources on absolute accuracy. To control for the effects of point accuracy distribution, the same control network was used for all the mosaics (Table 1), varying only the *apriori* values based on whether the NAC DTM or the GLD100 was used as the radius source.

Table 2: Bundle Adjustment Parameters (subset)

	Minimal Parameter Set	Full Parameter Set	Relaxed Minimal Parameter Set
camera pointing parameters	velocities	accelerations	velocities
spacecraft position parameters	position	accelerations	position
overexisting/ overhermite	yes	yes	yes
Spacecraft position sigma	20	30	100
Spacecraft acceleration sigma	N/A	1	N/A
twist	no	yes	no
Camera angles sigma	0.01	0.01	0.01
Camera angular velocity sigma	0.01	0.01	0.01
Camera angular acceleration sigma	N/A	0.001	N/A
radius	yes	yes	yes

Of the test mosaics made, the most accurate were those created using NAC DTMs as radius sources and solving for a minimal number of tightly constrained jigsaw parameters, using the original pointing as *apriori* values as described above (Table 3). When the NAC DTM was not used or the *apriori* pointing parameters were loosened, the recorded errors showed that the pointing accuracy actually decreased as a result of the bundle adjustment, despite an improvement in visible seams (Table 3).

Conclusion and Future Work: Currently, the construction of highly accurate and seamless controlled mosaics is possible as long as highly accurate ground and radius sources exist, and the point uncertainties, bundle adjustment parameters and number of parameters are very tightly constrained. Disconcertingly, however, any relaxation of these constraints results in larger offsets over some portions of an image than the pointing uncertainties would suggest necessary, especially as the offsets continue to increase with relaxation of parameters and point uncertainties. In light of this observation, it becomes difficult to trust even those displacements with magnitudes within the pointing accuracy. Future work, then, will necessarily involve further characterizing the effect of various bundle adjustments on the absolute accuracy of LROC NAC controlled mosaics. Production of highly accurate and well-controlled mosaics of key features of interest for release to the PDS will continue as well.

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Table 3: Solution Error Analysis (subset)

	1	2	3	4
Radius Source	NAC DTM	NAC DTM	NAC DTM	GLD100
Parameter Set	Minimal	Full	Relaxed Minimal	Minimal
Sigma0	0.563	0.530	0.532	0.594
Residual Std. Dev. (pixels)	0.180	0.135	0.150	0.252
Maximum Residual (pixels)	4.012	3.99	3.97	3.81
Mean Offset (meters)	9.792	11.988	13.462	31.286
Maximum Latitude Offset (meters)	16.906	23.912	29.904	39.015
Maximum Longitude Offset (meters)	-9.382	-12.790	-9.760	-20.035

PDS4 Product Search and Query Models

Steven Hughes and Sean Hardman

The PDS4 Information Model defines the labels for PDS4 Products. Upon ingestion into the PDS4 registry, a subset of the information in these labels is harvested to support search services. For example, every PDS4 Product must include a logical identifier, version identifier, and title. Optionally a product label should include a processing level, purpose, description, publication year, and a list of keywords. From this list, a query model can be defined by identifying the specific attributes to be harvested and how they are to be utilized for search within the search service. This presentation will describe the search service and its components and how the query models are defined and used to configure the search service.

LUNAR MODELING AND MAPPING PROGRAM PRODUCTS – A PLANETARY DATA SYSTEM ARCHIVE.

C. E. Isbell, P. A. Garcia, T. M. Hare, B. A. Archinal, L. R. Gaddis (Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, Arizona 86001, cisbell@usgs.gov.

Introduction: NASA's Lunar Modeling and Mapping Program (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 past and recent lunar datasets. Delivery of these products was planned via the LMMP web portal (http://lmmp.nasa.gov/) in support of the Constellation Program (CxP) [1-9] as well as other lunar exploration and research activities. LMMP critical goals included providing high-resolution and cartographically controlled data sets for "...landing site evaluation and selection, design and placement of landers and other stationary assets, design of rovers and other mobile assets, developing terrain-relative navigation capabilities, and assessment and planning of science traverses" [7]. For CxP, 50 sites of high scientific interest (CxP regions-of-interest or ROIs) were targeted specifically by the Lunar Reconnaissance Orbiter Camera (LROC) to obtain high-resolution stereo image coverage so that intensive characterization of each site could be conducted, and delivered to waiting exploration and science teams [4-6] in a timely fashion. Based on these site characterization products, each of the 50 sites was then to be examined as a potential landing site for further intensive exploration by humans as part of the CxP [1].

We now plan to capture these important LMMP data products and associated documentation within a Planetary Data System (PDS) archive. This effort will preserve and make accessible the LMMP data products, including mosaics, digital elevation models (DEMs), and derived slope, hillshade, and confidence maps for the 50 ROIs for future scientific research.

Significance of LMMP Data Products: The LMMP data products are important resources in support of current and future scientific research and exploration activities on the Moon and other Solar System bodies. The 50 ROI sites (Figure 1) were identified after an extensive process of input and evaluation by the US national lunar science community [6]. Each ROI had scientific or operational characteristics that warranted its selection as a potential site for future robotic or human landings. While human exploration of the Moon may be delayed, these sites remain of high science interest to the international lunar science community. For example, detailed site characterization and analyses of remote sensing data for the ROIs at former Apollo landing sites contribute significantly to our understanding of regional and local hazards [10], position of artifacts and location of critical components of the lunar geodetic network [11], geologic and geophysical context of samples [12], effects of topography on remotely observed characteristics [13], communications requirements at landing sites [14], and the physical properties of soils [15]. Additionally, LMMP data products can provide invaluable knowledge for future landing site planning and development of surface operational maps on bodies other than the Moon, including asteroids [16, 17] and satellites such as Phobos and Deimos. Finally, future proposals regarding high-interest sites such as the South Pole-Aitken Basin on the lunar far side [18] would benefit from LMMP products, including detailed information on the topography, slopes and roughness of the surface, crater size and distributions, boulder populations, and hazard and lighting maps [19].

The LMMP Data Collection: Several different types of data products were produced for the ROIs under the auspices of the LMMP. Institutions involved in generation of LMMP data products include the U. S. Geological Survey, University of Arizona, Arizona State University, NASA Ames Research Center, and NASA's Jet Propulsion Laboratory. The LMMP data collection includes regional and local visible-wavelength image base maps of the Moon derived from the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (~50 cm/pixel), Apollo Metric Camera (~20 m/pixel) and Panoramic Cameras (as high as 1-2 m/pixel). These high resolution controlled base maps are essential for visualization and mapping and modeling activities, including "draping" over surface Digital Elevation Models (DEMs).

The LMMP collection also includes regional- and local-scale lunar digital elevation models (DEMs) for almost all of the 50 ROIs. Topographic models provide visual elevation and slope references for science support and mission planners and crew. In addition to the image base maps and DEMs, the LMMP generated products for assessing landing safety and/or hazards at each site, including hillshade, slope, and confidence maps. Because the LMMP data products are geodetically controlled, the images and other relevant lunar surface data products allow users to correlate at known levels of accuracy the different types of information contained across the various data products. The total estimated digital volume of the LMMP data products to be archived under this proposal is approximately 700 GB.

The Archive Plan: A Planetary Data System (PDS) archive provides public access to both data products and accompanying ancillary support files. All archived data and supportive ancillary products will be compatible with the new PDS4 standard, an eXtensible Markup Language (XML) based architecture to ensure long-term usability and preservation of LMMP products.

Data and Metadata Conversion. All archive products will require descriptive PDS labels. In this case, a conversion process will involve the generation of related labels by utilizing and parsing existing metadata as provided by the LMMP project. In addition, the existing LMMP products will require conversion from existing data formats to PDS compliant formats.

PDS label design and generation. PDS labels are required for describing content and format of all entities within an archive. PDS labels will be generated so as to identify and fully describe the organization, content, and format of data products, documentation, and accompanying ancillary information.

Documentation, Metadata, and Ancillary Files. Supplementary reference materials will be formulated and included with archive products to improve their long-term utility. These documents augment product labels and provide further assistance in understanding the data and accompanying materials.

PDS4 model design requirements result in high level documentation and cataloging for all aspects of the archive. This intentional content provides the mechanism by which the archive will ultimately be ingested within the PDS to enable long term and integrated search and retrieval capabilities via PDS web services.

Peer Review. A peer review will be conducted after completion of the archive to ensure the data and supporting entities are complete, scientifically useful, and are in compliance with PDS standards.

Data Delivery to the PDS and NSSDCA Deep Archive. The finalized archive will be ingested into the PDS along with a copy sent to the National Space Science Data Center Archive (NSSDCA) for deep archive.

Delivery Schedule: This two-year project starts with data conversion testing and preparation along with initial documentation preparation for the first year. Final products and full archive population will occur in year two. Full access to LMMP data and supporting ancillary products is anticipated for September 2017.

Acknowledgement: This work is supported by NASA under a pending contract issued through the Planetary Science Division - Planetary Data Archiving, Restoration, and Tools (PDART) Program.

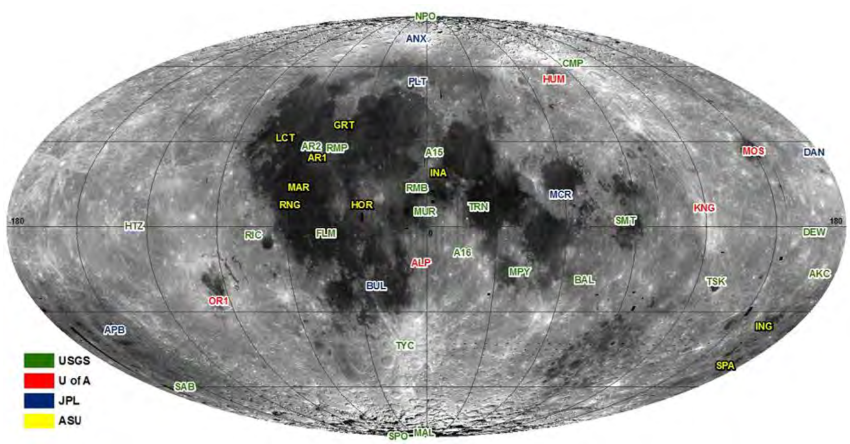

Figure 1: LMMP DEMs and Mosaics local-sites per facility (site name details to be provided at workshop).

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Color Contrast and Differentiation in Interactive Cartography A. J. Johnson, N. M. Estes, School of Earth and Space Exploration, Arizona State University, Tempe, Arizona, ajohnson@ser.asu.edu

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) Science Operations Center (SOC) deploys the Lunaserv Web Map Service (WMS) software in support of both internal and external data visualization needs [1]. The most common use case for Lunaserv is rendering multiple vector layers over a basemap. The extreme color range and variation encountered in Lunaserv basemaps can be seen by comparing the WAC global (Fig. 1) [2] and the WAC GLD100 color shaded relief (Fig. 2) [3]. The WMS client is free to overlay a basemap with any combination of available layers, in any order. This creates a challenge: rendering several easily visible layers (often only a pixel wide) over a background that may contain any color, and may change rapidly as the user pans and zooms. Addressing this challenge requires a set of colors that contrast with almost any background, and every other color in the set.

Approaches for Color Categorization and Differentiation: There are several color catalogs that help to describe colors in a consistent and reproducible language. The Inter-Society Color Council/National Bureau of Standards (ISCC-NBS) color catalog [4, 5] and the standard list of "web safe" colors [6] served as starting points for research. Existing sources of color coding and differentiation were investigated, including filing systems (Fig. 3), transit system maps (Fig. 4), Kenneth Kelly's twenty-two contrasting colors [7], USGS recommendations [8], and the color alphabet [9]. Different methods of generating sets of contrasting colors algorithmically were also researched. Most of the methods found involve operating in hue-saturation-lightness (HSL) color space and applying a fixed or slightly varying number to saturation and lightness, while dividing the hue spectrum into even intervals [10]. The resulting color set must be converted back into the red-green-blue-alpha (RGBA) color space for the WMS software. To more directly meet the needs of Lunaserv, an algorithm was devised to generate colors with maximum contrast based in the RGB color space [11]. This method divided the RGB space into intervals with values mathematically most different from one another, with the hypothesis that colors that are most mathematically different are also most visually distinct.

Selection of Color Set: Requirements for the color set included: 1) maximum visual contrast in any layer configuration with any basemap, 2) sufficient in quantity to render eighteen distinct layers, and 3) meeting the needs of color-blind users as much as possible. Colors from each source were overlaid on several basemaps and tested with human viewers for contrast against the base layer.

Results: "Web safe" colors proved irrelevant, as the list was designed to accommodate 8-bit color screens, which were superseded in the early 1990s [12].

The color algorithm successfully identified a list of maximally mathematically different colors; however, they were not the most visually distinct, as seen when comparing those colors rendered over a basemap (Figs. 5, 6) with Kelly's colors rendered over a basemap (Figs. 7, 8). The insufficiency of mathematical difference highlights the complicated nature of the problem, namely, that complex optical factors involved in human vision.

In the end, we found that Kenneth Kelly's list of 22 contrasting colors [7] from the ISCC-NBS color catalog [4] most successfully matched our priorities and constraints. The first nine colors in Kelley's list were carefully chosen to contrast even for people who are rd-green colorblind (based on the earlier work of Deane Judd [13]), and there was minimal overlap between this color set and the dominant colors of the various lunar basemaps in Lunaserv. Where overlap existed, the colors were removed or de-prioritized.

Conclusions: Selection of contrasting colors is a much more complicated problem than *prima facie* appearance, as human optics introduce a complex variable into the process. Previous research into the topic of color selection continues to be highly useful, even in applications far more complex than were available at the time of the research.

Figure 2: LROC WAC Global Mosaic [2].

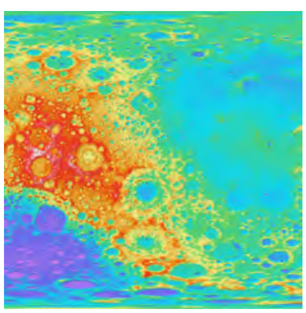

Figure 1: LROC WAC GLD 100 Color Shaded Relief [3].

Figure 3: Example of color coded filing system.

Figure 4: Example of color coding on a transit map.
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Anecdotally, some colors from the final set, when overlaid as vector layers on basemaps with highly similar colors, were still visually discernible, because the geometric nature of the vector layer itself provided sufficient textural contrast to clearly identify the layer. The effect of textural contrast on visual contrast may represent an important future area of research.

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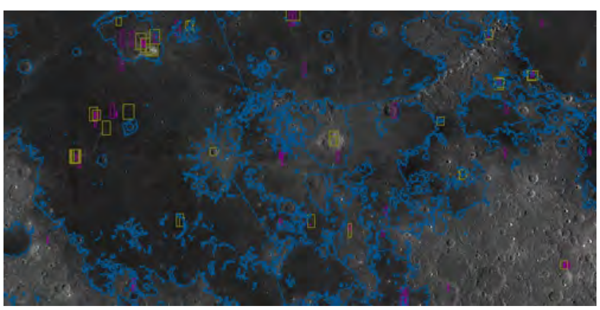

Figure 5: WAC Global Mosaic [2] with three RDR vector layers showing the algorithmic color selection.

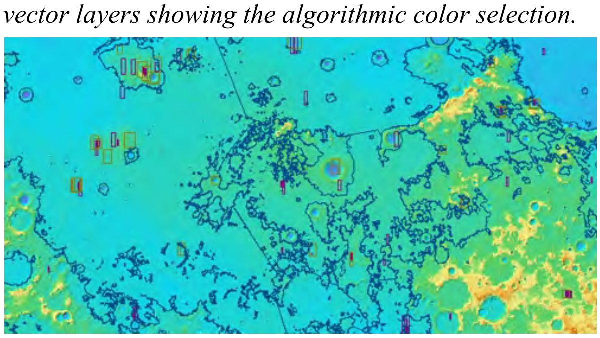

Figure 6: WAC Global Mosaic [2] with three RDR vector layers showing the algorithmic color selection.

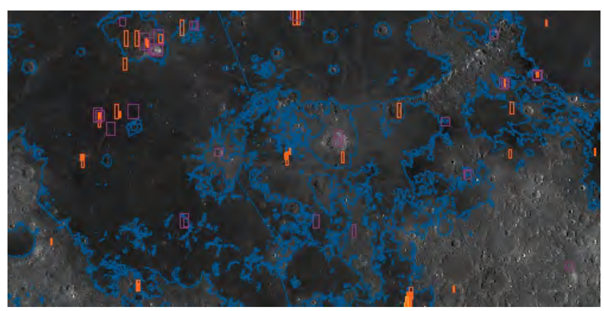

Figure 7: WAC Global Mosaic [2] with three RDR vector layers showing the final color selection.

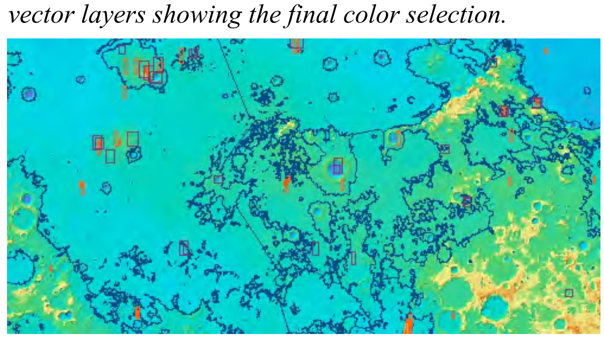

Figure 8: WAC GLD 100 color Shaded Relief [3] with three RDR vector layers showing the final color selection.

Computer Vision and Automated Boulder Counting on the Asteroid Bennu

Carina Johnson
OSIRIS-REx
University of Arizona

Fast and accurate rock and boulder detection is important to the goals of the OSIRIS-REx mission. Boulder identification and classification by hand, while accurate, is a slow, labor-intensive endeavor. The use of computer driven rock detection and classification algorithms would allow for automatic, real-time analysis of the size density distribution of rocks and boulders on Bennu's surface. Historically, rocks have presented a challenge to typical computer vision pattern matching frameworks. They have no uniform shape, texture, or size. Additionally, edges and contours are difficult to detect in situations where rocks are stacked, have unusual structures, or are partially buried. Because of this, no single algorithm can be expected to perform accurately in all rock and soil situations. However, current space science missions, particularly the Mars Exploration Rovers Spirit and Opportunity, have increased interest in and need for a robust, flexible group of rock detecting algorithms that can be mixed and matched to best suit a particular situation. Recent work has focused on performing individual segmentation using different characteristics of rocks including size, shape, texture, and shading, then combining and comparing the results. On average the accuracy of the combined results is significantly higher than the accuracy of the individual algorithms. Bennu presents additional challenges, the most significant being that we will not have clear images of the surface until after the spacecraft has launched, limiting the amount of time available to customize a suite of useful algorithms. However, the significant advancements in computer vision technology in recent years and access to diverse practice data (from Mars, Itokawa, and Ceres as well as images we have produced in our lab) will allow us to create a robust toolkit which can be adapted to Bennu's particular surface to allow for fast and accurate boulder identification.

THE OSIRIS-REx CAMERA SUITE CALIBRATION PIPELINE. E.K. Kinney Spano[1], J.I. Ivens[1], D.R. Golish[1], C.D. d'Aubigny[1], B. Rizk[1], University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, USA (ekinney@orex.lpl.arizona.edu).

Introduction: The Origins Spectral Interpretation Resource Identification Security - Regolith Explorer (OSIRIS-REx) sample return mission launches in 2016 with the objective of returning a pristine sample of regolith from Near-Earth asteroid Bennu[1]. A key data product from the mission will be the images from the OSIRIS-REx Camera Suite (OCAMS)[2]. The OCAMS images will be the primary inputs to several key image products for the mission including image mosaics, base maps, digital terrain models and orthoimages. Additionally, images will be analyzed to identify important features on Bennu that, along with other mission-generated data products, will help guide sample site selection. Features that are of particular interest to the OSIRIS-REx sample site selection decsion makers include spacecraft hazards such as craters, large boulders and areas rich in loose sampleable regolith on the surface of Bennu.

Calibrating raw OCAMS images is the first step in creating scientifically accurate and asthetically pleasing image products. The OCAMS calibration pipeline will automatically remove instrumental noise signatutres from the raw OCAMS images and calibrate the images to provide radiometrcally corrected images in physical units of W m^{-2} sr^{-1}. These images will be futher processed into image mosaics and base maps using statndard software tools such as the U. S. Geological Survey's (USGS) Integrated Software for Imagers and Spectrometers (ISIS) digital image processing software package. Stereo data products such as Digital Terrain Models (DTM) and orthoimages will be created using the commercial photogrammetry package SOCET SET ® distributed by BAE Systems, Inc.

Methods: The OCAMS calibration pipeline has been developed using the IDL programming language. The OCAMS pipeline was developed in the IDL Development Environment and the capability to run the OCAMS pipeline in IDL's interactive environment has been very helpful during OCAMS instrument development for instrument system testing and OCAMS ground calibration. The ability to run the OCAMS pipeline interactively will be maintained thoughout the OSIRIS-REx mission to aid in the developement of the OCAMS in-flight calibration program and to assist when needed OCAMS instrument anomaly resolution.

During routine mission opeartions the OCAMS pipeline will be run automatically in the OSIRIS-REx Science Processing and Operations Center (SPOC) within the IDL Virtual machine (VM). The IDL VM will allow the OCAMS pipeline to operate in batch mode in a multi-threaded environment. This mode of pipeline operation will allow seamless creation of calibrated images within minutes of image ingest at the SPOC. Calibrated images can be evaluated using web tools provided by SPOC personnel.

The OCAMS pipeline starts immediately after the completion of image ingest at the SPOC. The SPOC ground system kicks off the pipeline using a pipeline controller. A top-level master IDL procedure controls the sequence of the calibration steps to be performed. The algorithm for each step in the pipeline process is encapsulated in individual IDL functions. Parameters controlling the operation of each step in the pipeline are supplied by a comma separated value file that is read by the master IDL procedure. The master IDL procedure passes the relevant parameters to each IDL correction function.

The first steps in the pipeline perform standard image denoising corrections such as bias and dark current subtraction, charge smear correction and flat-field division. The denoised, uncalibrated images (level 1) are stored as FITS files in the OSIRIS-REx data repository. The next steps in the pipeline apply radiometric calibration factors and perform bad pixel and cosmic ray identifcation. The calibrated images (level 2) are also stored in the OSIRIS-REx data repository as multi-extension FITS files. The first extension in the calibrated images have been cosmetically corrected for bad pixel and comsic rays and the second extension flags the uncorrected bad pixel and comsic ray with special pixel values.

Input calibration files for the calibration pipeline were derivied from OCAMS detector characteriztion and engineering testing activities.[3]

Results: The beta version of the OCAMS pipeline was delivered to the OCAMS instrument team and the OSIRIS-REx SPOC in October 2013. This initial version of the pipeline was used in early ground system development and in the OCAMS Engineering Qualification Unit testing program.

Updates to the OCAMS pipeline were delivered in September 2014 to support the OCAMS flight model testing program and in April 2015 to support continued SPOC ground system integration activities.

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PYTHON FOR PLANETARY DATA ANALYSIS. J.R. Laura, T. M. Hare, L.R. Gaddis, R.L. Fergason, Astrogeology Science Center, U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ, 86001, jlaura@usgs.gov.

Introduction: Following our earlier publication on this topic [1], we continue to see increased utilization of the Python programming language by the planetary science community. A cursory search of the LPSC abstract archives shows a small, yet increasing number of abstracts explicitly making mention of access to underlying libraries via Python [e.g., 2, 3], the development of data processing capabilities within Python [e.g., 4-8], or the development of analytic solutions [e.g., 9-14]. These abstracts offer concrete examples of Python usage for processing and working with planetary data. We attribute this increase to the ease of use, readability, and portability of Python [1] as a scientific computing language. Python is commonly applied to High Performance Computing tasks and in the prototyping and development of Graphical User Interfaces, in continuing to leverage legacy code bases. This abstract reports our efforts to continue to integrate Python into our workflows and highlights additional use cases of potential benefit across the planetary science community.

High Performance Computing: Planetary data volumes are increasing rapidly due to increased data acquisition efforts associated with recent and new missions, improved spatial, temporal, and radiometric sensor resolutions, and increasingly complex process models generating ever increasing derived products [e.g., 15]. At current and future data sizes, tractable analysis requires either quantitative, repeatable methods of data reduction or the utilization of High Performance Computing (HPC) resources. Since the publication of the Atkins report [16], considerable research effort and funding has been invested in the development of Cyber Infrastructure (CI) projects. This suggests that the larger research community has avoided large-scale reduction and embraced HPC utilization. CI is the multi-tiered integration of HPC hardware embodied by distributed computing resources, "Big Data" sets, scalable processing capability, and collaborative, cross-domain research teams. Within the context of CI, Python is ideally suited to support the development of scalable high performance algorithms and the deployment of tools to reduce the complexity of HPC utilization that is within the CI middleware layer[22].

At USGS Astrogeology, we have utilized Python for the automated generation and submission of HPC jobs (e.g., Portable Batch System scripts) for the creation of Mars Odyssey Thermal Emission Imaging System (THEMIS) derived imagery [23] and the creation of rendered and animated 3D flyovers, as a full stack development environment to create RESTful services to expose underlying computational libraries through web based interfaces [18], and in utilizing HPC resources through the IPython notebook interface for proof-of-concept exploratory, big data analysis of the Kaguya Spectral Profiler data set [e.g., 19]. Scripted job submission has provided an easy-to-use interface for requesting and using HPC resources as if they are a local computer script. The development of a RESTful web interface to an analytical library provides the capability to hide the utilization of HPC resources from the end user, significantly reducing complexity. Finally, the use of IPython notebooks and a computing cluster for many-core exploratory data analysis has provided an ideal interactive environment for the development of metrics for use in larger scale automated analysis methods[1].

For the development of parallel, scalable algorithms Python offers three primary tools. First, the built-in multiprocessing module is ideal for Symmetric Multiprocessing (SMP) machines (e.g., desktop computers) where a single shared memory space is advantageous. This type of parallel computation is often used when processing large raster datasets. Second, vectorization, supported by the Numerical Python (NumPy) library, provides significant speedups for vector or matrix based computation. Image and spectral data processing are primary applications of this type of serial performance improvement technique. Finally, The Message Passing Interface (MPI) for Python (mpi4py) package offers Python native access to the MPI standard. More complex parallelization efforts, such as spatially constrained optimization, can significantly benefit from higher levels of communication across a highly distributed system.

We continue to identify use cases for high performance data storage formats, such as use of the Hierarchal Data Format (HDF5) for the storage of photogrammetric control networks and complex model output such as the multilayered thermal-diffusion model (KRC model [17]). In conjunction with Pandas, a Python library originally developed for robust big data quantitative financial analysis, there have been significant data storage reductions (due to compression) and analytical performance improvements (due to robust underlying algorithms). Future work will focus on providing concurrent access

1 See http://tinyurl.com/q76qkod for an example

to these data structures in HPC environments for scalability testing.

Legacy Code Bases: The redevelopment of an existing code base in a new language can be a costly, ill-advised endeavor due to the aggregate time already invested in the original development and the difficulty in regression testing between implementations. To that end, f2py and the Python native CTypes libraries provide two invaluable tools for wrapping legacy Fortran and C code, respectively. While the complexity of the wrapping scales with the complexity of the underlying code, we note that most Fortran subroutines are immediately wrappable with simply the definition of a few variable types. Likewise, wrapping of a C (or C++) library requires minimal additional development. Assuming that a complex legacy system can be split into smaller components, code portability can be readily realized. The additional development can be focused external to the algorithm logic, helping to reduce the potential to introduce bugs.

While f2py and CTypes frequently find application working with legacy systems, significant benefit can be realized with actively developed code bases. In the context of an HPC system, the ability to write and wrap small algorithm components in low level, high performance languages, while still maintaining rapid development via a higher level language is essential. This is primary reason why Fortran, C, and Python are considered dominant HPC languages. In practice, we most frequently apply this approach when performing a sequential operation for which vectorization is unsuited.

IPython / Jupyter: The IPython project [20], recently renamed to Jupyter, is composed of a local, lightweight web server and browser-based interface which allows for development, inline images, and LaTeX or MarkDown structured mathematics. In addition to Python, IPython also supports other environments and languages, for example Julia, Haskell, Cython, R, Octave (a MatLab alternative), Bash, Perl, and Ruby. We find extensive application of IPython notebooks for exploratory data analysis in the context of model development and validation, local and remote data access testing, for example in reading complex binary data structures, GUI development where an interactive window is spawned from within a web browser, interfacing with our HPC resources, and finally portability of analytical methods and results to collaborators. For this final use case, shipment of a single, Javascript Object Notation (JSON) file and any supplemental data files, e.g. Planetary Data System (PDS) image file, is all that is required for complete reproducibility. Each instance of an IPython notebook is run local to a single desktop computer and the new Jupyter project offers the ability to run a single access server to a distributed set of users.

Graphical User Interface Development: Python provides an ideal platform for the development of high end Graphic User Interfaces (GUIs), as well as stand-alone visualizations. Libraries such as PyQt, PySide, WxPython, and Tkinter offer access to robust GUI development libraries. At USGS Astrogeology, we have developed multiple cross-platform, stand-alone GUI interfaces in pure Python using PySide to call the Qt4 library. These tools are rapid to develop, robust to maintain, and relatively straight-forward to deploy.

Conclusion: Use of Python for scientific computing and data processing in planetary science is well underway. While research projects at USGS are now using Python tools, the tools generally are not made public for more general use. We are currently exploring ways to integrate both existing and new Python software into the USGS Astrogeology ISIS software [e.g., 21 and references therein] so that more general planetary applications can be realized.

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LUNAR AND VESTA WEB PORTALS. E. Law[1], Lunar and Mapping Modeling Project Team[1], [1]Jet Propoulsion Laboratory, Califronia Institute of Technology.

Introduction: The Lunar Mapping and Modeling Project is a collaborative project led by Solar System Exploration Research Virtual Institute (SSERVI) at NASA's Ames Research Center. JPL leads the engineering and implement, and USGS leads the data product generation working with various missions. The project has developed two web-based Portals: Lunar Mapping and Modeling Portal (http://lmmp.nasa.gov) [1] and Vesta Trek Portal (http://vestatrek.jpl.nasa.gov) [2] providing a suite of interactive visualization and analysis tools to enable users to access mapped Lunar and Vesta data products from past and current lunar missions (e.g., Lunar Reconnaissance Orbiter, Apollo) and from the Dawn mission.

The Portals allow users to explore and measure the surface, zooming in and out of the Moon and Vesta. The interactive maps are provided with different overlay options that provide details including visualization of various types of data (e.g., topography, mineralogy, abundance of elements and geology etc). These maps are value-added products based on data available from the Planetary Data System (PDS) [3]. The Portals also provide 3-D printer-exportable topography so users can print physical models of the Moon's and Vesta's surface. For Vesta, standards keyboard gaming controls are available to maneuver a first-person flyover view across the surface of Vesta.

We will give an overview of these Portals and live demonstration of their features.

References:

[1] http://lmmp.nasa.gov/
[2] http://vestatrek.jpl.nasa.gov/
[3] http://pds.nasa.gov/

ADDRESSING STRATEGIC PLANNING NEEDS FOR PLANETARY CARTOGRAPHY.

S. J. Lawrence[1], B. A. Archinal[2], L. R. Gaddis[2] [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (sjlawren@asu.edu) [2]U. S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, USA

Introduction: Cartography is the science and practice of placing information in a standards-compliant, community-recognized spatial framework. The goal of planetary cartography is to enable any conceivable science investigation with returned planetary mission data, now or in the future. Archived standards-compliant cartography products are a resource that continues to produce scientific benefits for decades after a planetary mission is complete, much like how the Apollo lunar samples continue to enable a steady stream of new discoveries as analytical instrumentation has steadily improves.

Planetary cartography enables science investigation and human exploration planning for all planetary bodies. However, cartographic products involve major efforts in time and research to properly execute. For this reason, strategic planning for planetary cartography is essential for successful planetary science research.

Here, we briefly outline the history of NASA strategic cartography planning and issues where the community-driven capabilities provided the newly-established NASA Cartography Research Assessment Group (CRAG) will facilitate future effective NASA strategic planning.

Background: Historically, planetary cartography has involved broad segments of the community. During the Apollo era, multiple organizations helped to plan and carry out the work, including the United States Geological Survey (USGS), NASA Johnson Space Center, the National Geodetic Survey, the Defense Mapping Agency, RAND, academia, and others. The table below lists the various groups that have historically been established to coordinate these efforts, disseminate information to the broader community, and advise NASA on cartographic matters [1].

The last of these, the PCGMWG, includes broad representation from the planetary science community and includes the Geologic Mapping Subcommittee (GEMS). Other groups have been active in making recommendations on mapping standards (e.g., IAU WGCCRE, 1976-present; MGCWG, mid-'90's-present; LGCWG, 2007~2009) but not general cartography planning [2-4].

Start Date	Name
1974	Lunar and Planetary Cartography Committee
1977	Lunar and Planetary Photography and Cartography Committee
1979	Planetary Cartography Working Group
1994	Planetary Cartography and Geologic Mapping Working Group

From 1994 to 2012, the PCGMWG made cartography recommendations to NASA, including submitting a white paper on cartography [5] to the NRC Decadal Survey. The PCGMWG ceased making cartography recommendations in 2012. The group continues its other responsibilities, primarily an annual External Review of the NASA Planetary Cartography program. Currently, no entity is charged with NASA strategic cartography planning

CRAG: To address this issue, the NASA Planetary Science Subcommittee has endorsed the formation of CRAG to serve as a community-based resource to coordinate NASA strategic planning needs for planetary cartography. As presently envisioned, the responsibilities of CRAG are projected to include:

(1) Provide findings concerning the scientific rationale, objectives, technology, and long-range NASA strategic priorities for geologic mapping, geospatial software development, and cartographic programs;
(2) Assist, through the activities of Specific Action Teams, with developing cartographic, planetary nomenclature, and geologic mapping standards for present and future NASA flight missions and research activities
(3) Providing findings regarding the accuracy and precision required for cartographic technologies and products
(4) Help to coordinate and promote the co-registration of datasets from international missions with those from US missions.

In principle, these activities will help enable flight missions and the broader planetary science community to widely leverage planetary geospatial science data and products to make ongoing research discoveries. At the present time, CRAG is intended to potentially carry out three discrete functions to carry out its responsibilities:

Strategic Program Analysis: CRAG will be responsible for reviewing and prioritizing the cartoplanetary cartography objectives represented in past, present, and future NASA flight mission operations, research and analysis programs, cartographic research, geospatial software development, and geologic mapping programs. CRAG provides findings in response to requests from HEOMD, SMD, the Space Technology Mission

Directorate (STMD), and the NASA Advisory Council (NAC).

Community Liaison: CRAG will maintain a close liaison with the NASA Science Mission Directorate (SMD), the Human Exploration and Operations Mission Directorate (HEOMD), the NASA Space Technology Mission Directorate (STMD), other Assessment Groups, Federal mapping agencies, allied space agencies, and relevant international coordination entities (e.g., the International Astronomical Union, or IAU). CRAG will promote international collaboration, to help enable the broad spectrum of geospatial data products and programmatic capabilities required to effectively execute robotic precursor and human exploration of the Solar System, which include (but are not limited to) the science analysis of planetary surfaces, the identification of safe landing sites, the down selection of sample acquisition locations, hazard assessment, and the geospatial characterization of in-situ resources.

Standing Review Panel: It is intended that CRAG can assume the role historically held by the current PCGMWG and maintain a standing peer-review capability, should NASA require a future External Review of the cartography-related program elements in the NASA research and analysis portfolio. This function is similar to how the NASA Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) maintains standing peer-review panels to assess the allocation of extraterrestrial materials in the NASA collection.

Issues: There are numerous high priority issues that CRAG and the larger planetary science community must address in the years and decades to come. These issues include:

- How should the current, unprecedented influx of planetary mission data sets, (e.g., the Mars Reconnaissance Orbiter, the Lunar Reconnaissance Orbiter, MESSENGER) be geodetically controlled and integrated to enable science and operation of current and future missions?
- How should global, regional and local topographic models be created from multiple available data sets?
- What requirements should be developed for missions to follow during the formulation and definition stages to prevent subsequent cost-growth?
- How can research and analysis programs support development of mapping procedures for large scale and complex products?
- How can cartographic products be used to enable and facilitiate future human exploration and in-situ resource utilization? [6]
- When and how should mapping tools be developed and how should they be tested for accuracy and user-friendliness?

As an example of the kind of in-depth assessment that the community-driven expertise coordinated by CRAG can help facilitate, many needs exist for new or improved tools to handle the increasingly complex instruments and vast data volumes of current and planned missions. Examples include (1) faster and more robust matching between disparate data types, enabling new types of data fusion; (2) ability to simultaneously adjust data from different platforms (e.g., orbital, descent, lander, and rover) and data types (e.g., images, radar, and altimetry); (3) new tools to combine different methods for generating topographic information, especially combining LIDAR and image-based techniques. In the current budget environment it is impossible to develop all the desired tools concurrently, and so the community must prioritize desirable capabilities that can be enabled by near-term investments in software tool development.

Conclusions: The planetary science community faces numerous issues relating to NASA strategic cartography planning for the coming decade and beyond as the United States aims to carry out ambitious planetary missions throughout the Solar System. By involving key stakeholders in the process and inclusively building an active and productive cartography community, CRAG can and will help NASA and the community effective prioritize cartography needs and drive future discovery and innovation.

Additional Materials: An extensive historical archive of additional background materials related to the history of planetary cartography strategic planning can be found at:

http://astrogeology.usgs.gov/groups/nasa-planetary-cartography-planning

References: [1] PCWG, 1993, "Planetary Cartography 1993-2003". [2] Archinal, B. et al., 2011, *Cel. Mech. Dyn. Ast.*, 109, 101. [3] Duxbury, T. et al., 2002, http://astrogeology.usgs.gov/search/details/Research/ISPRS/Duxbury/pdf. [4] Archinal, B. et al., 2009, *LPS XL*, #2095. [5] Johnson, J. et al., 2010, http://www.lpi.usra.edu/decadal/sbag/topical_wp/JeffreyRJohnson.pdf. [6] Wargo, M. et al., 2013, *IAC 64*, IAC-13-A3.1.4

RESTORATION AND SYNTHESIS OF LUNAR GEOCHEMICAL AND PETROLOGICAL SAMPLE DATA TO SUPPORT FUTURE SCIENCE (MOONDB). K.A. Lehnert[1], C. Evans[2], N. Todd[2], R. Zeigler[2] [1]Lamont-Doherty Earth Obseravtory, Columbia University, 61 Rt 9W, Palisades, NY, 10964, USA; lehnert@ldeo.columbia.edu, [2]Johnson Space Center, full mailing address and e-mail address).

Introduction &n Rationale: Over more than 45 years, the nearly 2,200 samples that were collected on the Moon during the Apollo missions have been made available to the global research community for studies that have helped expand our understanding of the history and evolution of the Moon and our solar system. A vast body of petrological, geochemical and geochronological data has been amassed that remains highly relevant for current and future science, but that is to a large extent not accessible in a digital format that makes the data easy to access and re-use. Investigators who want to use lunar sample data in their research are currently required to compile and transcribe data from disparate sources including publications in digital or analog format and from PDF files such as those of the Lunar Sample Compendium (Meyer 2012, [LSC]), and/or they need to contact their colleagues for unpublished data or data compilations. This is a serious obstacle for the use and exploration of the lunar sample data to create new scientific insights.

MoonDB Objective & Scope: Over more than a decade, data systems for igneous petrology and geochemistry such as PetDB, GEOROC, and NAVDAT have created and maintained large-scale online geochemical synthesis databases that have revolutionized data access in these fields and established themselves as essential resources for Geoscience research, facilitating new, more quantitative statistical approaches and leading to new discoveries. MoonDB will use the concept and architecture of the PetDB data system (http://www.earthchem.org/petdb) to advance the access and utility of lunar sample data for future research restoring data from the literature as well as unpublished legacy data, integrating them in an online accessible, quality-controlled data system, and providing a user interface with tools to search, filter, and explore the data, and generated customized subsets of the data as needed for a specific science question.

Developement of MoonDB: The development of MoonDB comprises several tasks: 1. adapt the PetDB data system to lunar sample data and metadata. This includes modifications to the database schema, which is based on the Observation Data Model ODM2 [1], [2] to controlled vocabularies, data entry tools, and PetDB's graphical user interface to fully align the system with requirements for lunar sample data storage, search, display, and retrieval; 2. compiling data and relevant metadata from published scientific articles, from the Apollo Sample Compendium, and from datasets contributed by researchers, preparing them for ingestion into the database (formatting, harmonizing terminology), and loading them into the database with appropriate data quality control procedures; 3. linking data in MoonDB to data available in other databases at JSC, at the Lunar and Planetary Institute, and in the Planetary Data System (e.g. imagery of specimens and thin sectios, sample descriptions, physical properties, sampling history, etc.) to advance discovery and access of lunar sample data and the development of a lunar information network; 4. develop the MoonDB Reference Catalog that will integrate references from all relevant databases.

Data Rescue: Many lunar geochemical data are unpublished and in danger of being lost forever as researchers, especially those who generated the initial suite of lunar sample data in the 70's and 80's, retire or pass away. Part of the MoonDB project is an effort to encourage and help investigators who are in possession of unpublished lunar sample data restore, publish, and archive these data for inclusion in MoonDB. This effort will not only enhance MoonDB's comprehensiveness and utility, but also rescue these data for the long term. Eleven senior lunar researchers are part of the project and have committed to contributing their data. Further data contributions will be encouraged through workshops at relevant conferences such as the Lunar and Planetary Science Conference, GSA Annual Meeting, and Goldschmidt Conference. Contributed data will published via the EarthChem Library (http://www.earthchem.org/library), following international best practices including DOI registration and their long-term preservation in appropriate archives such as the Planetary Data System.

Management & Operation: The MoonDB project will be managed within the organizational structure and well-established technical infrastructure of IEDA (http://www.iedadata.org), a data facility that operates and maintains data systems and services for solid Earth data, including the EarthChem data systems and the System for earth Sample Registration. IEDA is a member of the World Data System.

References:

[1] Horsburgh J. et al. (2013 *AGU Fall Meeting Abstracts*, 1197. [2] Lehnert K. A.. et al. (2014) *Geophys. Res. Abstr.* 16, EGU2014-12113.

MARSSI: A DISTRIBUTED INFORMATION SYSTEM FOR MANAGING DATA OF THE SURFACE OF MARS. L. Lozac'h[1], C. Quantin-Nataf[1], P. Allemand[1], B. Bultel[1], H. Clenet[1], S. Harrisson[1], D. Loizeau[1], A. Ody[1], P. Thollot[1], [1] Laboratoire de Géologie de Lyon: Terre, Planètes, Environnements, Université Lyon 1/ENS Lyon/CNRS UMR 5271, 2, rue Raphaël Dubois, 69622 Villeurbanne cedex, France, Email : loic.lozach@univ-lyon1.fr

Introduction: Geological investigations of planetary surfaces are based on the exploitation of orbital data and often acquired with different remote sensing instruments. For Mars, for instance, the number of missions and instruments and the size of the datasets are so important that even at the scale of a single scientific team, an information system to manage data is more and more required.

The creation and exploitation of a database of Mars surface is part of the e-Mars project funded by the European Research Council (ERC), the aim of which is to decipher the geological evolution of the planet from the combination of Martian orbital data. We have designed a distributed information system called MarsSI to manage data from the four following Martian orbiters: Mars Global Surveyor (MGS), Mars Odyssey (ODY), Mars Express (MEX), and Mars Reconnaissance Orbiter (MRO). MarsSI allows the user to select footprints of the data from a web-GIS interface and download them to a storage server. Then the user can process raw data via automatic calibrations and finally acquire "ready-to-use" data of Mars surface. "Ready-to-use" means that the data are ready to be visualized under Geographic Information System (GIS) or remote sensing softwares. An automatic stereo-restitution pipeline producing high resolution Digital Terrain Models (DTM) is also available.

Project's development: MarsSI has been developed using a Two Tracks Unified Process (2TUP) [1] which is an iterative software development process framework, that starts with the study of the functional needs of the end users, here the e-Mars team members. The functional architecture's study has revealed that the team needed an easy to use web-GIS application for selecting, downloading and processing large amount of Mars imagery data. On the other hand, a technical architecture's study is performed, and a Java based project has been retained with the following open source projects: Geomajas [2] for the web-GIS application, Spring [3] for the server-side services and dialog with the database, GeoServer [4] to publish images' footprints, PostGreSQL [5] as database server with PostGIS [6] functionalities, TORQUE [7] as resource manager for jobs scheduling. The project disposes of a local storage server coupled with a compute cluster to launch the calibration scripts.

Application architecture: MarsSI has been developed as a 3-tiers web application. The web-tier is based on Geomajas framework and coded with Google Web Toolkit (GWT) [8] libraries. The services-tier is based on Spring framework and provides the functionalities determined by the user's needs. It communicates with the web-tier via Geomajas command pattern, and with the data-tier via Spring's Data Access Object (DAO) pattern. The data-tier is a PostgreSQL database storing the input/output entities needed in the workflow of the application's services. It also stores Mars imagery footprint's geometry and attributes thanks to PostGIS functionalities.

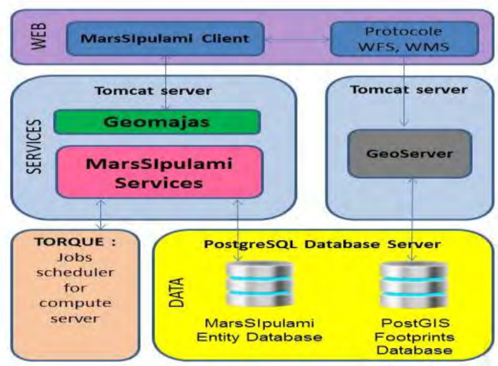

Figure 1: MarsSI architecture.

The basic workflow is the following: the footprints provided by the NASA Planetary Data System (PDS) [9] are published in WFS protocol from the PostGIS database by GeoServer. Geomajas makes them visible on screen via its web-GIS interface. The user is allowed to do searches and selections with the different GIS tools provided by Geomajas, and then the MarsSI Services creates jobs on user's demand. Those jobs scheduled are and launched by TORQUE on the compute cluster. These jobs can call any software installed on the compute cluster (ISIS3, IDL/ENVI, AMES Stereo Pipelines…). Both server-side and client-side have been simultaneously developed, they are adjustable so that the application can be regularly upgraded with new instrument data or new processing pipelines.

Functionalities: MarsSI is divided in two parts, a map view and a workspace view.

Data selection: The map view (Figure 2) shows a map of Mars with the common GIS tools (zoom, identifying, measurement, selection and search), a layer view to show/hide on map the footprints available, and a table in which the user can add the selected footprints. This table shows image's information as name, geometry, status and link to its PDS on-line label file.

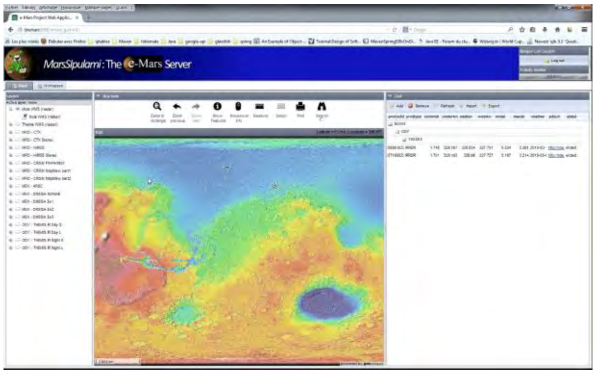

Figure 2 : MarsSI user interface – map view

Data processing: The workspace view (Figure 3) is divided in 5 tabs: cart view, download view, calibration view, projection view and stereo-restitution view. The cart view allows the user to check the localization of the added footprints on a map, to know the status of the data that are being processed and to copy the ready-to-use data to a personal ftp account on the storage server.

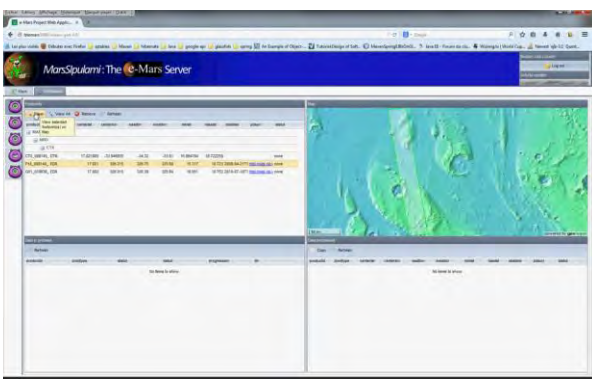

Figure 3 : MarsSI user interface – workspace view

If the data are not already stored on the local server, they appear in the download view, and the user can launch the download from the PDS server. Once the download is accomplished, the data appear in the calibration view. Once the calibration is done, the data appear in the projection view. The user can now launch the map-projection of the data.

To date, MarsSI handles CTX, HiRISE and CRISM data of MRO mission, HRSC and OMEGA data of MEX mission and THEMIS data of ODY mission. CTX, HiRISE and THEMIS raw data are processed with ISIS3 functions. CRISM images are processed with the CRISM Analysis Toolkit (CAT) [10] and OMEGA data are processed with IDL pipelines (team released pipeline).

Stereo-restitution: The stereo-restitution pipeline is functional for HiRISE and CTX images. CTX and HiRISE possible DTM footprints are computed, according to the following constraints: image couples with 60% width-overlapping and a minimum deviation of 10° in emission angle. It is user's responsibility to check the quality of the stereo pairs, thanks to their PDS on-line label files. Then, the user can choose one or several stereo footprints from the map view and they appear in the stereo-restitution view. If the raw image couple is not stored on the local server, MarsSI automatically adds the 2 images to the user's cart and ask him to process the data before launching the stereo-restitution application. A script inspired from Zack Moratto's blog [11] has been written. This script uses the NASA Ames Stereo Pipeline toolkit to process the stereo images and automatically obtain DTM.

Conclusion: The teamwork engaged under the e-Mars project has allowed the creation of an application that fully matches the needs of our team of Martian geologists, allows the integration of new data processing chains, and offers standardized and distributed storage/compute resources. The application has also been designed to deal with other planetary targets. The next step of MarsSI, the Martian surface database application, will be to open up to the Martian community.

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INTERACTIVE WEBMAP-BASED SCIENCE-PLANNING FOR BEPICOLOMBO. J. P. McAuliffe[1], S. Martinez[1] and Iñaki Ortiz de Landaluce[2], [1]ISDEFE for The European Space Agency (ESA), European Space Astronomy Centre (ESAC), Camino bajo del Castillo, s/n Urbanización Villafranca del Castillo, Villanueva de la Cañada, E-28692 Madrid, Spain. [2]Serco for The European Space Agency (ESA), European Space Astronomy Centre (ESAC), Camino bajo del Castillo, s/n Urbanización Villafranca del Castillo, Villanueva de la Cañada, E-28692 Madrid, Spain. Contact: jonathan.mcauliffe@esa.int

Introduction: For BepiColombo, ESA's Mission to Mercury, we plan to build a web-based, map-based interface to the Science Planning System. This interface will allow the mission's science teams to visually define targets for observations and interactively specify what operations will make up the given observation. This will be a radical departure from previous ESA mission planning methods. Such an interface will rely heavily on GIS technologies.

Details: This interface will provide footprint coverage of all existing archived data for Mercury, including a set of built-in basemaps. This will allow the science teams to analyse their planned observations and operational constraints with relevant contextual information from their own instrument, other BepiColombo instruments or from previous missions. The interface will allow users to import and export data in commonly used GIS formats, such that it can be visualized together with the latest planning information (e.g. import custom basemaps) or analysed in other GIS software.

The interface will work with an *object-oriented concept of an observation* that will be a key characteristic of the overall BepiColombo science-planning concept. Observation templates or classes will be tracked right through the planning-execution-processing-archiving cycle to the final archived science products.

By using an interface that synthesizes all relevant available information, the science teams will have a better understanding of the operational environment; it will enhance their ability to plan efficiently, minimize or remove manual planning steps and maximize the science return of the mission. Interactive 3D visualization of the planned, scheduled and executed observations, simulation of the viewing conditions and interactive modification of the observation parameters are also being considered.

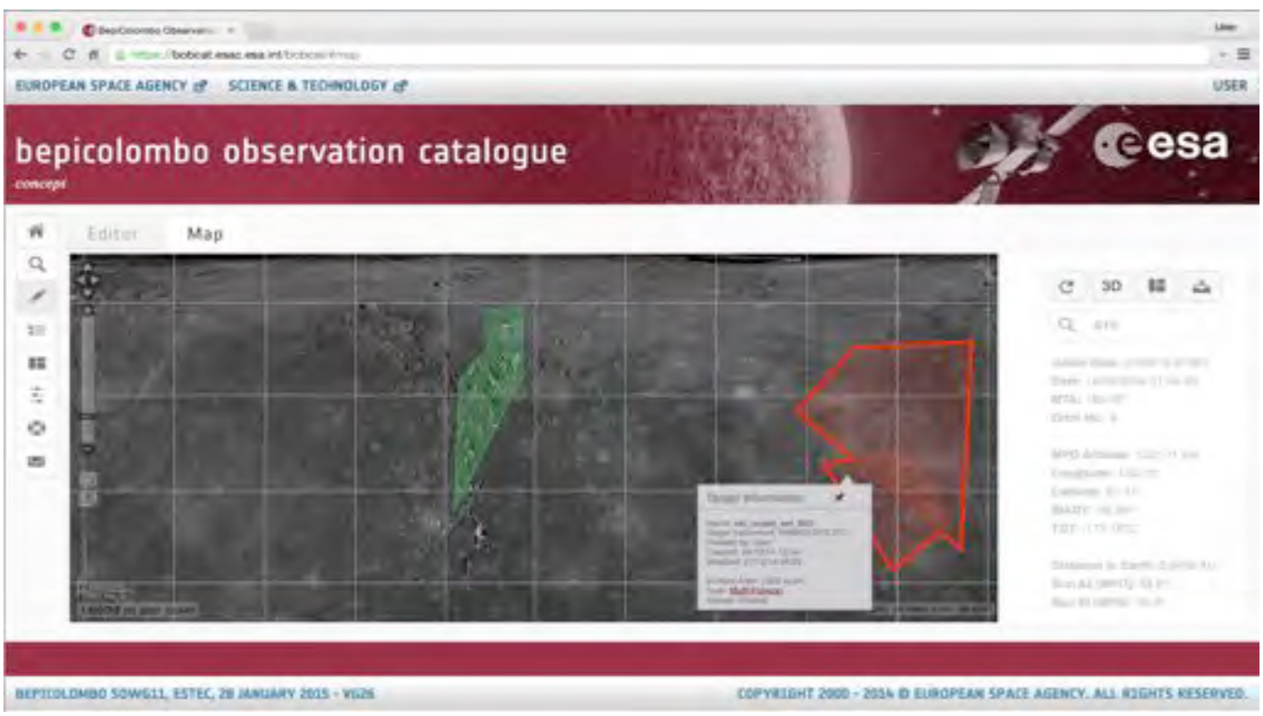

Figure 1: Mockup of the map interface of the BepiColombo Observation Catalogue. Users can interactively specify areas on the map and (1) define them as areas for observation or (2) query previously collected or planned data for that area.

Lunaserv Global Explorer, 3D. C. E. Miconi, N. M. Estes, E. Bowman-Cisneros, M. S. Robinson, School of Earth and Space Exploration, Arizona State University, cmiconi@ser.asu.edu

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) Science Operations Center (SOC) develops and maintains Lunaserv Global Explorer (LGE) to support internal operations, researchers, and public interfaces to the LROC data [1]. LGE is capable of visualizing map data in a 2D interface from any Web Map Service (WMS) compatible geographic information system (GIS) software. In addition to the currently capabilities of LGE, a 3D spinning-globe interface to visualize map data is a commonly requested item by both researchers and the public. To satisfy this demand, the LROC SOC is developing a new WMS client software package, Lunaserv Global Explorer 3D (LGE 3D).

LGE 3D utilizes the glob3mobile (G3M) toolkit to introduce this capability independent of platform and leverages all the existing capabilities of the Lunaserv WMS software (Fig. 1) [2]. G3M is a multi-platform visualization framework for making applications that map and visualize various forms of geographic data. G3M is capable of rendering raster maps, terrain, vector data, 3D objects, and symbols from multiple sources. LGE 3D enhances G3M to provide planetary capabilities and a reliable mechanism for retrieving terrain data directly from WMS.

Platform Independence: One of the useful features of G3M is its platform independence, which enables the resulting application, LGE 3D to run inside of web browsers and on the two largest mobile device platforms (iOS and Android). This platform independence allows LGE 3D to reach the largest number of users. Minimal support for complex 3D interfaces like LGE 3D exists on mobile devices, so the capability to provide a native application on these platforms provides a better experience with expected functionality including full multi-touch support, integration into each platform's menu system, and other native application interactions (Fig. 2). Most importantly, G3M's support for the Android and iOS platforms also provides hardware graphics acceleration on those mobile devices.

3D Terrain Support: The G3M framework experimentally supports the rendering of terrain through WMS servers. There are currently a limited number of WMS servers capable of serving full bit-depth terrain at the required resolution. Of the WMS servers capable of serving terrain, many users report that these WMS servers respond with incorrect elevation values under heavy load or when the view area becomes too large [3]. The Lunaserv WMS server is capable of serving full bit-depth terrain at high-

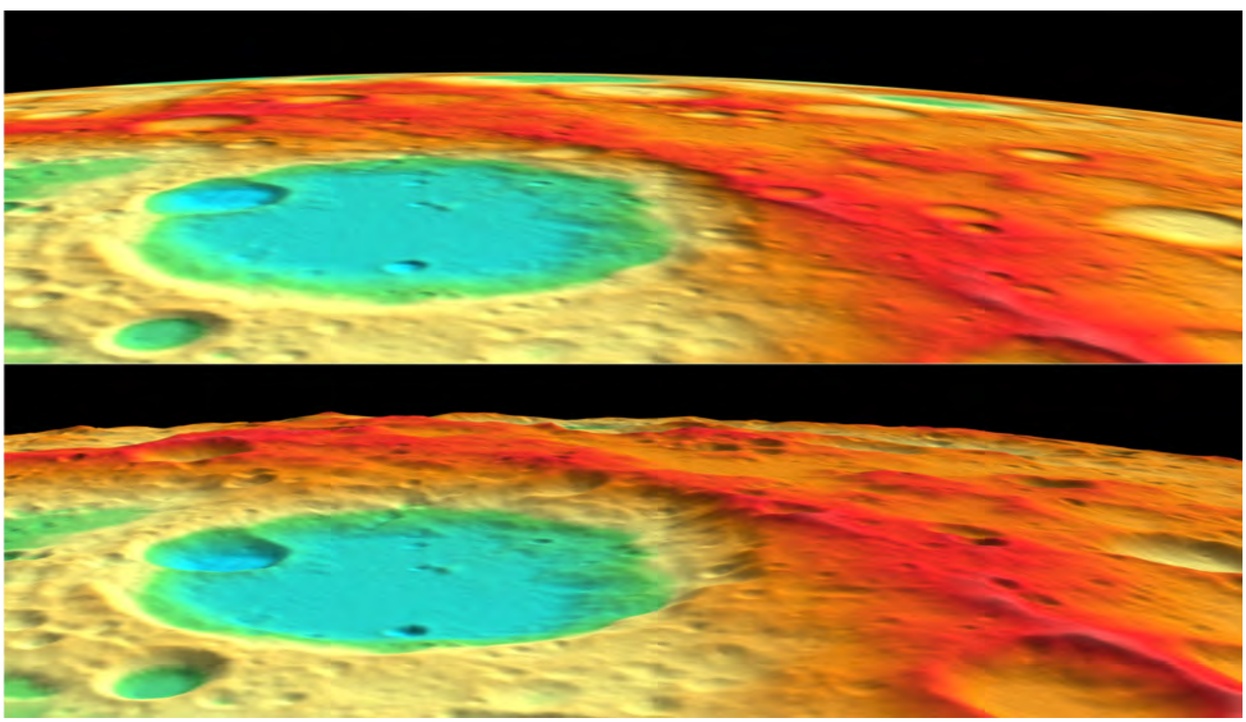

Figure 1 Top: GLD100 color shaded relief rendered in LGE 3D without 3D terrain. Bottom: The same view rendered in LGE 3D with GLD100-based 3D terrain enabled. [4].

resolution and based on extensive testing under load is proven to respond correctly to any number of requests.

With this support, LGE 3D is capable of rendering terrain over the entire globe for any planetary body supported by Lunaserv, for which a digital elevation model (DEM) exists (Fig. 3). The DEM layer loads dynamically via WMS and is automatically scaled and loaded as the zoom-level and orientation of the view change.

For users wanting to serve their own terrain data using Lunaserv, the built-in numeric layer type produces the correct tiles from an ISIS cube source DEM.

3D Interface: LGE 3D renders the map as a dynamic 3D globe either based on a spherical model or with DEM-based terrain. The dynamic globe allows users to pan and rotate the globe to achieve the desired view. Additionally, the view allows adjustment to any angle or direction to facilitate oblique views of the base map and for better visualization of rendered terrain.

Figure 2: Screenshot of prototype LGE 3D Android app showing the WAC Normalized Reflectance map with dynamically generated illumination based on the GLD 100 DTM [4,5].

Potential Enhancements: Additional effort can go into improving performance of LGE 3D. When loading terrain, LGE 3D puts additional load on Lunaserv that previous 32bit layer consumers, such as JMARS, do not, so further optimization in the Lunaserv numeric base layer type could improve performance. G3M could also be optimized to allow for additional parallel loading of basemap tiles to increase rendering speed.

LGE 3D will be tested with irregularly shaped bodies and if it cannot handle the data, we will attempt to modify the source code. If G3M can be made to handle these shapes, LGE 3D could then be used for visualization of asteroids, comets, and other small satellites.

G3M is capable of rendering small 3D models both in orbit (i.e. spacecraft models), and on the surface (i.e. rovers and landers); future versions of LGE 3D could take advantage of these capabilities along with view scripting to construct interactive 3D tours.

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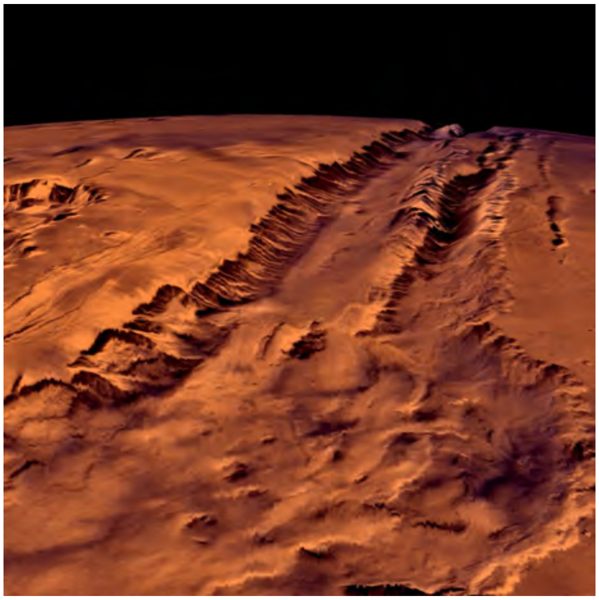

Figure 3: Mars Viking basemap rendered in LGE 3D using the MOLA DEM for the terrain.

MRO/HiRISE RADIOMETRIC CALIBRATION UPDATE. M. P. Milazzo[1,⋆], K. Herkenhoff[1], K. Becker[1], P. Russell[2], A. Delamere[3], A. S. McEwen[4]; [1]Astrogeology Science Center, U.S. Geological Survey, [2]Smithsonian Institute, [3]Delamere Support Services, [4]University of Arizona; ⋆(moses@usgs.gov)

Introduction: The High Resolution Imaging Science Experiment (HiRISE) onboard the Mars Reconnaissance Orbiter (MRO) [1] has been observing Mars since 2006 and has acquired more than 38,000 observations of the martian surface. The HiRISE instrument is a pushbroom imaging system made up of fourteen linear, two-channel, Charge Coupled Devices (CCDs). Ten 2048-pixel-wide CCDs with a broadband red filter (RED CCDs) are laid side-by-side with an overlap of 48-pixels on each side for a total of 20,264 pixels. In front of and behind the RED CCDs, as viewed in the along-track direction, are four more CCDs, two each with a blue-green (BG CCDs) and near-IR (IR CCDs) filter respectively (Figure 1). The HiRISE instrument thus consists of 28 separate channels calibrated independently.

Radiometric calibration is a critical step in image analysis; without it, quantitative comparisons of colors and brightnesses between observations and between instruments would be impossible. To-date, because of a lack of accurate radiometric calibration, most martian studies using HiRISE images have been morphological in nature. Once radiometric calibration has been finalized, inter- and intra-instrument brightness, color, color-ratio, and spectral studies will be possible. For example, quantitative comparisons between the high-spectral-resolution imaging spectrometer, CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) and the high-spatial-resolution HiRISE will be possible [2].

The two channels on a given CCD are commanded with identical imaging parameters but contain separate electronics, so require independent calibration parameters. The two main imaging parameters that affect radiometric calibration are TDI (Time Delay and Integration) and binning. TDI is a method for increasing signal by capturing up to 128 lines of data over a single ground point; TDI modes of 8, 16, 32, 64, and 128 are possible. Each CCD may be binned over 2x2, 4x4, or 8x8 blocks of pixels, increasing signal to noise at the expense of spatial resolution. The calibration routines operate on each of these TDI, BIN combinations for each of the 28 CCD channels. A schematic of a HiRISE channel's calibration data is shown in Fig 2:

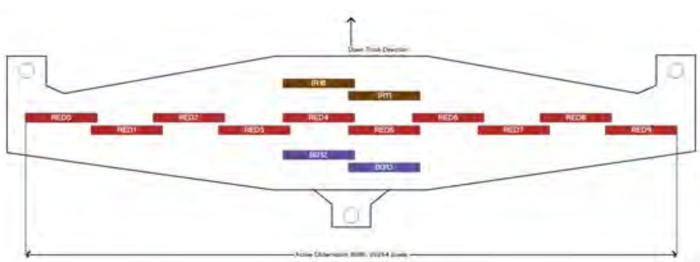

Figure 1: *Schematic of the HiRISE Focal Plane Array. The IR CCDs observe the ground first, then the RED CCDs, and finally the BG CCDs.*

* **Pre-Observation Lines:** For each sample, data are acquired immediately before the image observation lines from three distinct calibration sources.
  - Reverse Clock Pixels: 20 lines of offset signal.
  - Masked Pixels: charge generated in the active area of the CCD is transferred, one line at a time, through 20 lines of pixels behind a mask.
  - Ramp Lines: Number of lines equally to TDI ÷ BIN. These include initial signal from the reverse and forward clocking through the CCD. For a flat target and no dark current or offset, the last Ramp line should have twice the signal of the image line immediately following.
* **Pre-Image Samples:** The Buffer Pixels comprise 12 samples read out of the serial register before each image line. These Buffer Pixels only contain serial dark current and offset.
* **Post-Image Samples:** The Dark Pixels comprise the 16 pixels at the end of each line of the CCD. These pixels were masked from exposure by metallization deposited onto the CCD and should only contain serial and parallel dark current and offset signal.

Radiometric Calibration: Below, we describe the radiometric calibration requirements and what has been accomplished to date to meet those requirements.

Scattered Light: The HiRISE baffle system was designed for the minimization of scattered light from the disk of Mars with a goal of less than 2% of the nominal signal. HiRISE acquired observations of Phobos for analysis of scattered light. Scattered light was undetectable in the well-planned images, and from those analyses we conclude that scattered light contributes at most 0.22% and more probably 0.1% or less.

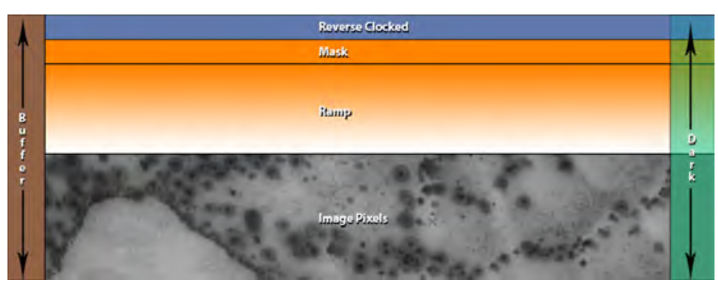

Figure 2: *Schematic of the structure of the raw HiRISE image channel as delivered to the PDS.*

Relative (Pixel-to-Pixel) Calibration: The requirement for HiRISE relative calibration was that calibrated pixels would exhibit better than 1% pixel-to-pixel accuracy for 99.5% of the pixels within each CCD and across the FOV when using 128 lines of TDI. Relative accuracy of 1% is required over a 10-second image exposure.

Flat-field calibration data were acquired in the laboratory before launch and at Mars by yawing the spacecraft 90-degrees to the direction of travel. These data indicate a relative pixel-to-pixel accuracy of less than 0.5%. A more accurate number, with full error analysis will be presented at the conference.

A 10-second exposure of an average brightness surface will produce an observation of approximately 100,000 lines, assuming 100 μs line exposure time which is typical of science imaging. Night-side calibration images were generally taken with fewer lines for a number of operational reasons. On a 2.5-second exposure, electronics-induced noise drifts by approximately 1.7% ($\sim$20-DN), but this effect is measurable using the Buffer Pixels. Our accuracy in correcting the drift *for a night-side, dark image* is approximately 1.4% ($\sim$20-DN) over 2.5-seconds, though the largest drift occurs during the first 1-second (10,000 lines) and there appears to be minimal drift after about 50,000 lines. The absolute value of this error in measuring the drift is independent of the target (because it is electronics noise rather than photon-generated), and is approximately 20 DN. For a well-exposed science image with average DN of 4000 or more, the error is 0.5% or better.

The analysis of the relative calibration across the full observation FOV will be presented at the conference. At this time, we are confident that the Reduced Data Records (RDRs) released to the PDS have relative accuracy on a per-channel-basis of 1% or better for a well-exposed surface image with TDI=128 and better than 2% across the FOV.

Absolute Calibration: The absolute calibration accuracy requirement was 20% or better in all channels using 64 TDI lines. Because HiRISE is a linescan/pushbroom imaging system, standard stellar calibration targets are not as useful for absolute radiometry as they are for framing cameras. The special calibration sequence we performed with Jupiter is phase-, time-, and thus model-dependent. Special calibration sequences with the Moon and Earth have proven difficult to analyze due to imaging geometry and because the observations taken during cruise have few comparable observations during science operations. The martian moons have been observed by too few independent instruments for high quality comparisons. We have been forced to compare HiRISE images of the martian surface with much lower-resolution imaging systems such as Hubble, CRISM, and MARCI. Our absolute calibration is within 20% of the calibration of those instruments, but we have not yet verified the calibration against well-established standard calibration targets.

Spectral Response: As a goal, the relative spectral response of each pixel over the entire FOV should be 5% accuracy from 400 to 1100-nm in steps of 50-nm. Calibration of the spectral response is similarly complicated by the lack of standard calibration targets. Based on laboratory measurements before launch, the relative spectral response of the three HiRISE filters is 4%.

Signal to Noise Ratio: The requirement for signal to noise (SNR) is 100:1 for RED CCD data acquired at 300-km altitude when imaging the martian surface with average albedo of 0.25, 70-degree incidence angle, and when Mars is at its average distance from the sun (1.5 AU) with imaging parameters of 128 TDI and BIN 1. For the same situation (except with an average albedo of 0.1), the BG CCDs are required to have SNR of at least 25:1 and the IR CCDs 50:1. The HiRISE SNR is generally much higher (200:1 or better for the RED CCDs and 50:1 or better for the IR and BG CCDs).

Conclusions: Results are summarized in Table 1.

Software: HiRISE Experimental Data Records (EDRs) are processed through the HiRISE Operations Center (HiROC) via a series of custom processing steps [3]. The key processing step is the U.S. Geological Survey Astrogeology Science Center's Integrated System for Imagers and Spectrometers, version 3 (ISIS3) application *hical* [4]. *hical* is the software that produces nominally calibrated products from the EDRs in the form of I/F or calibrated radiance values.

Additional Complications: Beyond instrument response, the martian atmosphere is variable from observation to observation and its effects are not included in these calibration efforts. Atmospheric effects must be accounted for when performing color ratios, comparing observations taken at different times, or comparing between multiple instruments.

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Table 1: Preliminary Calibration Results

Calibration	Requirement	Result
Scattered Light	2%	$< 0.22\%$
Relative	1%	$1 - 2\%$
Absolute	20%	Uncertain, $\sim 20\%$
Spectral	5%	4%
SNR	100 : 1	200 : 1

TOWARD COMMUNITY STANDARDS FOR SOFTWARE DATA MANAGEMENT IN PLANETARY SCIENCE. Chase Million[1], [1]Million Concepts, 2204 Mountainview Ave., State College PA 16801 (chase.million@gmail.com).

Introduction: Members of the Planetary Science community are being asked to consider new questions of software availability in the contexts of "open science" and "reproducible research." NASA's 2014 Research Opportunities in Space and Earth Science (ROSES) call contained at least one program that *required* dissemination of software products [1], and the 2015 call—in response to "NASA Plan: Increasing Access to the Results of Scientific Research" [2]—adds a new requirement for Data Management Plans which *may* include software [3]. Clear community standards for software sharing do not yet exist within Planetary Science, however, and it is time for software users and creators to start having open dialogues toward defining those standards.

Summary: Software is increasingly recognized in all scientific communities as both a first-order research product and, for many classes of investigation, nigh indistinguishable from methodology. Not only is publication of source code or otherwise making software and source code available important for modern research to be auditable and reproducible, but it serves as a way for future researchers to build on the work of their colleagues, potentially improving efficiency and the rate of scientific progress. It is also fast becoming a requirement of grants and publications. For historical, political, or structural reasons, other research communities have been openly and actively considering questions about software availability for years or decades, and we can learn from their decisions.

As a starting point for further discussion, we present trends in community standards for software sharing in other fields, particularly Astronomy, and responses to very common questions by scientists faced with the prospect of sharing their software. We also make suggestions for how historical approaches to data and knowledge sharing in Planetary Science can inform a community standard for software data management in light of these new requirements.

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DIGITIZING APOLLO LANDING SITE FEATURES AND TRAVERSES FROM LROC IMAGE DATA.
D. M. Nelson[1] and R. V. Wagner[1]. [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 (DavidMNelson@asu.edu).

Introduction: In preparation for the six landed Apollo missions, a large number of lunar surface features associated with the sites were identified and named. During extra vehicular activities (EVAs) at the each of the landing sites, the surface regolith was disturbed by the walking and roving astronauts. With the collection of high-resolution Lunar Reconnaissance Orbiter Camera (LROC) images at each of the sites, we are, for the first time, able to accurately map the locations of the surface features and traverses in a Geographic Information Systems (GIS) database. In order to map these features with a significant degree of accuracy, we used new global datasets derived from stereo imaging and laser altimetry for our basemaps. These datasets include the Global Lunar DTM (GLD100) model and the 100 m/pixel global mosaic. We georegistered high-resolution stereo images to our basemaps using SOCET SET to locate the Apollo surface features for digitization into an ArcGIS geodatabase. The resulting products will be released as shapefiles through the LROC Planetary Data System (PDS) node.

Global Base Images And Lunar DTMs: With the arrival of the Lunar Reconnaissance Orbiter (LRO) at the Moon in 2009, and its subsequent six years in orbit, images and surface measurements containing unprecedented detail have been acquired. Derived image products from these data provided the basis of mapping the Apollo surface features. Moderate resolution global images and high-resolution images of the six landing sites were brought into ArcGIS and projected onto the IAU2000 standard lunar coordinate system, in which the Moon has a mean radius of 1737.4 km [1].

For this project, two high-resolution global datasets were used. The first is a 100m/pixel global mosaic. Using images acquired between November 2009 and February 2011, the LROC team produced an image mosaic that was comprised of over 15,000 images. The images were geometrically projected to a lateral surface accuracy of ~40m [2] and photometrically corrected for a consistent representation of the surface albedo. In addition, the images used were acquired at a lighting incidence between 55°-70° for the most favorable lighting to reveal geomorphology.

The second product is a global digital terrain model (DTM). Through the combination of comprehensive image coverage by the LROC Wide-angle Camera (WAC) and the Lunar Orbiter Laser Altimeter (LOLA), a geodetically accurate 100 m/pixel Global Lunar DTM of the Moon (GLD100) was generated [3].

To visually identify the landing site features, we superposed multiple, overlapping sets of high-resolution (0.35-0.65 m/pixel) LROC Narrow-angle Camera (NAC) images that had been acquired under several different lighting angles. From the NAC stereo pairs of these sites, DTMs were generated using SOCET SET [4], to ensure the best surface registration of the surface features.

Named Apollo Site Surface Features: Planning for the Apollo lunar landings resulted in the naming of nearly 280 features associated with the six sites that would be visited by Apollo astronauts. 78 of these features were officially recognized by the International Astronomical Union (IAU), while 199 remained unofficially named. Although unrecognized by the IAU, these feature names were referenced by the astronauts and ground crew during the respective missions, and by the science community in literature following the missions. In the interest of historic preservation, we digitized all of the Apollo landing site features, which include craters, small massifs, fractures, and small maria embayments, into an ArcGIS geodatabase.

The initial part of our project was to update the 78 officially named landing site features (LSF). The coordinates of the LSF were obtained from the IAU list of official lunar nomenclature [5,6]. These coordinates were based on Lunar Obiter, which were poorly registered to the lunar surface, and laser ranging of the retroreflectors at the Apollo 11, 14, and 15 sites [7]. Using LROC NAC images and improved lunar geodesy, the LSF were easily identified, and the respective geographic coordinates and attribute table were updated.

Prior this work, the unofficially-named LSF (ULFS) had never been compiled in comprehensive GIS or mapped in a useful format. We researched Apollo-era documents, which include planning maps, annotated images, and voice transcripts, to compile all features and associated names that were referenced during the six Apollo landed missions [8]. Most labels in the documents plainly pointed to the intended feature, although some regional names had ambiguous placement (e.g., no leader, or the label was in a cluster of features), and a few feature names were not consistent between different maps of the same area (e.g., Lee-Lincoln; Double Dot). In a few cases, descriptive map annotations were incorrectly taken as feature names (e.g., "Double") and later removed. Like the LSF, the ULSF were mapped as point features in our geodatabase, and were given attributes of latitude, longitude, mission, and a status of "unofficial".

Apollo Science Payloads And Traverses: During their explorations on the surface of the Moon, the Apollo astronauts deployed science payloads and disturbed the regolith while walking or driving the Lunar Roving Vehicle (LRV). We mapped the resulting traverses into our geodatabase. To resolve details of the traverses required image resolutions of 0.35-0.7 m (although up to 2.0 m/pixel would reveal the presence of traverse but no detail). Utilizing images with differing incident light angles over the same area also helped to locate the traverses. Incidence values of 30°-60° were better in accommodating changing surface topography, whereas lower incidences, 0°-30°, provided better variations in albedo.

Deployed science payloads were identified by bright surface reflections, usually in association with a concentration of disturbed regolith. Where ambiguous, we reviewed post-mission documents to determine the name and location of the payload. Our mapping of these features is currently on-going.

The traverses were identified in the LROC-NAC images by two different morphologies. The walking traverses are generally broad, up to two meters wide, because the astronauts walked side-by-side or re-walked over same path. As a result, they are darker and not sharp-edged. This “muddy” appearance made the traverses easier to see on the NAC images, but detail was more difficult to discern, mostly in the case of over-printing. In this case, we solved the problem by placing a single line through densest part of the walking traverse.

The LRV tracks consist of two narrow, distinct, parallel lines, approximately 2.3 m apart, made by 23 cm wide wheels. They have less contrast than the walking traverses because the regolith does not appear to have been as disturbed as much. As a result, the clarity of the tracks are sensitive to solar incidence angle, the unevenness of terrain, and sometimes the direction of travel. In general, lighting conditions are best when the solar incidence was 45° to 60° and illuminated an E/W course. In many places the traverses were not visible. Mapping of these hidden traverses was mitigated by interpolation of a path between two visible ends of an apparent single line of travel. Where there was no obvious corresponding path of travel, we referenced the pre-mission planning maps or the voice transcripts made during the time of the traverse to infer a location.

Attributes added to the geodatabase include: traverse (EVA) number, traverse direction (away/return), and length (in meters) of the traverse segment between intersections.

In the mapping of traverses, the spacing of verticies along the path was dependent upon the image resolution and frequency of change in traverse direction. Where pixel resolution was about 0.5m/pixel, we digitized a vertex every 5-8m (10-16 pixels) for finer detail, and up to 20m (40 pixels) for straighter lengths.

Products Generated: When the projects are completed, there will be a five shapefiles for each of the six landing sites. There will be three pointfiles: updated LSF, ULSF, and science payload locations; and two line files: walking traverses, and roving traverses (the latter for Apollo missions 15-17). Shapefiles are considered proprietary/open source and can be used by a variety of GIS software. Each file will contain metadata, based on FGDC (Federal Geographic Data Committee) [9] standards. The finalized products will subsequently distributed through the PDS, LROC node, as part of the “extra” data products.

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A NEW GEOGRAPHIC INFORMATION SYSTEMS LAB: FACILITIES AND INSTRUCTION AT THE RONALD GREELEY CENTER FOR PLANETARY STUDIES. D. M. Nelson[1] and D. A. Williams[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 (DavidMNelson@asu.edu).

Introduction: The NASA Regional Planetary Information Facilities (RPIFs) provide images, literature, and education outreach pertaining to past and existing planetary missions. Over the last two years, we at the Ronald Greeley Center for Planetary Studies (RGCPS), the Arizona State University (ASU) RPIF, have added a Geographic Information Systems (GIS) computer laboratory to our facility. This GIS lab will be maintained by the RGCPS Data Manager, who will also instruct researchers on the use of GIS and image processing software. By providing planetary-based GIS training, we hope to encourage the scientific community to perform planetary research at the RGCPS.

The RGCPS: The RPIFs were established in the 1970s to: 1) archive photographs and literature from active and completed planetary missions, and 2) provide researchers and the public access to the archive for scientific research, future mission planning, and education/public outreach [1]. There are currently 9 US and 7 international RPIFs that continue to provide these services.

The RGCPS, formerly the Space Photography Laboratory (SPL), was established by Professor Ronald Greeley at ASU in 1977 as a branch of the U.S. Geological Survey RPIF [2]. SPL became a full, independent RPIF by 1982, and in 1992 it was moved to a 2740 ft^2 climate-controlled lab (Figure 1). After the death of Dr. Greeley in 2011, the facility was renamed the “Ronald Greeley Center for Planetary Studies”.

The purpose of the facility has always been to support planetary geology research for faculty, staff, and students, and to promote and disseminate the results of NASA Planetary Science Division missions (especially those associated with ASU, e.g., Mars Pathfinder, Mars Exploration Rovers, Galileo, and DAWN).

GIS At The RGCPS: With the advent of the Internet, many of the image data sets and literature, originally exclusive to the RPIFs, have become available electronically for download. While planetary data have become widely distributed, there is still a strong need for experts to educate potential users regarding planetary image formats and the software needed to ingest and process the data. For example, all planetary image data are archived electronically by NASA through the Planetary Data System (PDS) and freely available to the public. However, the data are not easily viewed by common commercial software (such as Adobe Photoshop™). In addition, most image data from planetary missions require a comprehensive database of camera-pointing information (e.g., SPICE kernels [3]) to correct for geometric distortion and balance photometry. Furthermore, there is a steep learning curve for the software that is used for planetary mapping, such as ArcGIS™ [4] (the licenses for which are very expensive), QGIS (a still-developing open-source, multi-platform GIS) [5], and Adobe Illustrator™ (a non-GIS graphic design software).

In early 2014, we began adding a digital planetary GIS laboratory to the RGCPS. There are five dedicated dual-screen GIS workstations with ArcGIS™ 10.2 [4] and JMars [6] installed in each of them. In addition, from these workstations researchers have access to ISIS 3 (Integrated System for Imagers and Spectrometers) [7], the de facto planetary image processing software, through an on-site Linux server. Our goal over the next five years is to develop GIS projects for all terrestrial planets, outer planet satellites, and the larger small bodies. The GIS databases in development include Io and Vesta, and, through a collaboration with the RPIF at Cornell University, Titan.

To facilitate training at the RGCPS, we are developing seminar-style classes on planetary GIS. These will consist of three or more hour-long sessions, including: an overview of the basic software components of ArcGIS™, the understanding and integration of image datasets into ArcGIS™, creating and editing vector data files, and projecting planetary datasets onto models of planetary bodies. Advanced seminars will include using ArcGIS™ as a planetary research tool, and the development of planetary mapping databases. Initially, these seminars will be made available to students and researchers at ASU, and then eventually for visiting planetary scientists in the American Southwest.

By reinventing the RGCPS as a digital planetary GIS laboratory, our goal is to facilitate planetary research by providing instruction for understanding and processing data from a variety of planetary missions.

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[3] ftp://naif.jpl.nasa.gov/pub/naif/ toolkit_docs/C/info/intrdctn.html [4] http://www.esri.com
[5] http://www.qgis.org/en/site/
[6] http://jmars.asu.edu
[7] http://isis.astrogeology.usgs.gov

Figure 1. The Ronald Greeley Center for Planetary Studies (RGCPS), at Arizona State University. The developing digital planetary GIS laboratory houses several computer workstations, each with licensed versions of ArcGIS, and contain global geodatabases of the terrestrial planets and satellites.

NASA PDS Imaging Node: Not Just A Data Archive. J. Padams[1], B. Deen[1], L. Gaddis[2], T. Hare[2], S. Lavoie[1], E. Sayfi[1], A. Stanboli[1], and K. Wagstaff[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [2]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ. (jordan.h.padams@jpl.nasa.gov)

Introduction: The Imaging Node (IMG)of the NASA Planetary Data System (PDS) is the home to over 700 TB of digital image archives, making it one of the richest data repositories for planetary imagery in the world. Within these archives the data comes in many varieties, whether it's orbital versus landed missions, original raw experiment data versus derived products, differing coordinate systems, etc. Tools and services are needed to integrate these data so information can be correlated across missions, instruments, and data sets.

IMG has developed numerous tools and services to support both the wide variety of available data but also to meet the needs of its broad user community, from the scientist analyzing a particular crater on Mars to a member of the general public browsing the Internet for the coolest image of Jupiter. Leveraging partnerships with the Multimission Ground System and Service (MGSS) Office, Machine Learning and Instrument Autonomy Group (MLIA), Media Relations, and Multimission Image Processing Lab (MIPL) at the Jet Propulsion Laboratory (JPL) and the the expertise in planetary science, cartography, geodesy, photogrammetry and science software development at USGS Astrogeology Science Center, IMG continues to push towards new tools and services that bring the data to the people and support significant scientific discovery. For example, data archived and supported by IMG have been used to discover water on the "bone dry" Moon (Moon Mineralogy Mapper data; [1]), recent geologic activity related to CO_2 frost in martian gullies (High Resolution Imaging Science Experiment data or HiRISE; [2]), recent impacts on the Moon and Mars (Lunar Reconnaisance Orbiter Cameras or LROC; [3]; HiRISE; [4]), and recent lunar volcanism (LROC; [5]).

Webification (w10n): Webification (W10N) (http://pds-imaging.jpl.nasa.gov/w10n/) is a specification that defines a common way to expose resources (composite files, databases, command-line applications, etc.) on the web. The core idea is to make the inner components of resources directly addressable and accessible via well-defined and semantically meaningful URLs. Webification provides access to applications (services) as well, through ReSTful URLs. This means that standalone applications can be transformed into web services through a component of Webification called Servicification (aka Serv10n API). This service is central to the server-side functionality for several IMG services, including the Planetary Image Atlas, PDS Marsviewer, and Landmarks Web Services.

Atlas III: Upgraded to version 3 in Fall 2014, the Planetary Image Atlas (http://pds-imaging.jpl.nasa.gov/search/) provides access to the entire collection of IMG data through links to online holdings and data node catalogs [6]. The PDS Imaging Node Atlas III utilizes faceted navigation, an interactive style of browsing datasets that allows users to filter a set of items by progressively selecting from only valid values of a faceted classification system. In the Atlas III, facets are defined by the most commonly used search criteria for imaging datasets including but not limited to: mission name, instrument name, target, product type, lighting geometry meta-data (emission angle, incidence angle, phase angle), lat/lon meta-data, time constraints, etc. In addition to the faceted approach, the Atlas III builds on the features of the previous Atlas including a map interface for the Saturnian moons, Earth's moon and Mars. The Atlas III also incorporates the use of the MGSS webification backend that makes use of the image transformation software developed by MGSS (MIPL) through javascript widgets [7]. Nearly 15 TB of data are delivered to users across the globe by the Atlas each month.

Photojournal: The Photojournal provides access to the "best of" planetary image collection from recent and current missions and offers image highlights, press release images, derived products such as mosaics and perspective views, and other image products. (http://photojournal.jpl.nasa.gov/index.html). JPL media relations jointly funds this service, and it delivers more than 4 TB per month to users, with more than 75 images added per month [6].

PDS Marsviewer: The Mars Image Viewer (Marsviewer) is an image viewing tool tailored to Mars in-situ (landed) missions (http://pds-imaging.jpl.nasa.gov/tools/marsviewer) [8]. It makes it easy to view original images (EDRs) as well as all derived image products (RDRs), such as XYZ maps, slope, reachability, mosaics, etc. Originally designed as a QC tool for the MER image processing team, it sees wide use throughout the MER, MSL, and PHX ops and science teams (with InSight and Mars 2020 coming soon). Leveraging the Webification (w10n) protocol, Marsviewer is now available for remote use as well through IMG for use by the general public to access and view Mars in-situ images and derived data (http://pds-imaging.jpl.nasa.gov/tools/marsviewer).

UPC/PILOT: The Unified Planetary Coordinates (UPC) database [9] addresses the problem of the multiple and disparate coordinate systems in which PDS image data can be delivered by standardizing all coordinates to 0° to 360°, and positive east longitudes for select image data. The UPC database is available through the Planetary Image Locator Tool (PILOT, [10] http://pilot.wr.usgs.gov/). PILOT provides an interface to select planetary targets on which users can specify a geographic bounding box and execute searches resulting in rendered footprints, thumbnails, and browse images. Users can restrict searches based on instrument and observational and (or) positional constraints (for example, incidence angle, solar longitude, pixel resolution, and phase angle). Complete or partial sets of resulting images can be retrieved using an automated download script. A newly added feature in PILOT now allows users to locate overlapping images (stereo-pairs) suitable for deriving topographic surfaces [10].

Landmarks Web Services: The Landmarks Services include an overlapping image finder, landmark detector, landmark classifier, and change detection (http://pds-imaging.jpl.nasa.gov/tools/landmarks). Using the UPC Pilot Database to determine an image's location, the overlapping image finder provides the ability to find overlapping images for a surface location of interest. Landmarks are visually salient surface features, such as dust devil tracks or dark slope streaks on Mars, that are detected using an approach known as dynamic landmarking [11]. Change detection is done by comparing the landmarks found in overlapping images taken at different times. The instruments currently supported by these services include Mars Global Surveyor MOC, Mars Odyssey THEMIS, and Mars Reconnaissance Orbiter HiRISE.

POW: The Map Projection (on the) Web Service (POW) is a free online service that transforms raw Planetary Data System (PDS) images to science-ready, map-projected images. POW uses PDS Imaging Node tools (PILOT and UPC) to locate images and then allows the user to select and submit individual images to be map-projected [12].

Map-A-Planet 2 (MAP2): An update to the existing Map-A-Planet of the PDS, MAP2 is an on-line tool for extracting science-ready, map-projected images from global mosaics. The web service stores the mosaics in a searchable document management system or data portal called Astropedia (http:// astrogeology.usgs.gov). Leveraging Astrogeology's ISIS3 (http://isis.astrogeology.usgs.gov), GDAL (http://www.gdal.org) and a local processing cluster [12], users can customize and download map-projected image maps of Mars, Venus, Mercury, the Moon, four Galilean satellites (Callisto, Europa, Ganymede, Io), five moons of Saturn (Rhea, Dione, Tethys, Iapetus, Enceladus), and now the asteroid Vesta.

PDS Annex: Formerly Astropedia Annex, the PDS Imaging Node Annex is a data portal to allow the ingest and cataloging for derived geospatial products generated from PDS holdings for individual scientists.. Examples of geospatial derived products are cartographic and thematic maps of moons and planets, local and regional geologic feature maps, topographic and perspective views of planetary landing sites, and tabular data containing unit information derived from planetary data. Many of these products have been developed as a result of NASA data analysis programs, often years after active missions (and their accumulating archives) have ended [13].

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TITANBROWSE: USING A NEW PARADIGM FOR ACCESS TO HYPERSPECTRAL DATA. P. Penteado[1] and D. Trilling, [1]Department of Physics and Astronomy, Northern Arizona University, NAU Box 6010, Flagstaff AZ 86011-6010, pp.penteado@gmail.com.

Introduction: There are many tools and standards that allow immediate retrieval of a variety of astronomical observations, mostly derived from the VO paradigm, but these are not applicable to remote sensing observations of Solar System bodies. While astronomical observations are confined to a 2D spatial domain (coordinates in the sky), with all objects always observed from essentially the same point of view, remote sensing observations span different perspectives. More elaborate tools are needed, both to evaluate the geometrical conditions of the observations, and to archive them in an accessible way. Here we present titanbrowse, a database, exploration and visualization system which solves these difficulties, to enable full use of all Cassini VIMS observations of Titan.

Cassini VIMS observations of Titan: VIMS is an imaging spectrometer that records in each observation (commonly called a data cube) 352 bands at 64×64 pixels each. Since the arrival of Cassini at the Saturn system, in 2004, until July 2010, approximately 2×10^4 cubes comprising 15×10^6 spectra were recorded. This makes it impossible for a user to directly examine all the spectra. A simple cube database, such as provided by PDS, is not enough, due to several limitations: 1) In each cube there is typically a large variation in observation geometry over the spatial pixels. Thus, often the most useful unit for selecting observations of interest is not a whole cube but rather a single spectrum (one spatial pixel). 2) The pixel-specific geometric data included in the standard pipelines has too few variables calculated (such as latitude, longitude, and illumination angles), and all the geometry is calculated at only one point per pixel. Particularly for observations near the limb, or at high relative velocities, it is necessary to know the actual extent of each pixel. 3) It is not possible to identify all the spectral features of interest by direct inspection. Thus, it becomes necessary to make database queries not only by metadata, but also by the spectral data. For instance, one query might look for atypical values of some band, or atypical relations between bands, denoting spectral features (such as ratios or differences between bands). 4) There is the need to evaluate arbitrary, dynamically-defined, complex functions of the data (beyond just simple arithmetic operations), both for selection in the queries, and for visualization, to interactively tune the queries to the observations of interest. 5) The process of making the most useful query for some analysis is typically interactive, with the user needing to explore how different functions of the data vary over the observations. This requires an efficient database (so that the queries are fast), and integration with a visualization system, so that queries can be quickly interactively changed. Having to export data to files, then import them into a visualization system, would usually make this process too slow and inefficient

Titanbrowse: These problems were the motivation for the development of a new database system for hyperspectral observations of planetary bodies, called titanbrowse, since we created it for Cassini VIMS observations of Titan [1]. The same solutions can be readily adapted for observations of other bodies by other instruments. The framework is particularly well-suited for other imaging spectrometers, currently a standard instrument on every Solar System exploration mission.

Implementation. We found that standard relational database software lacks key functionality needed to fulfill the requirements above. Titanbrowse was implemented in Interactive Data Language (IDL), since it provides these necessary features: 1) Efficient array processing and advanced array semantics: Archived hyperspectral data from cube files fit well into a read-only two-table database (one table for cubes, another for spatial pixels), where queries and processing can be well handled through vector operations on these tables, for which IDL is extremely well-suited. 2) The possibility of dynamically evaluating arbitrary functions of the variables (table columns). These functions are used both as the search criteria in the queries, and to interactively inspect the results and adjust the queries, and go beyond simple arithmetic and logical expressions (as in typical database systems). Changes can be freely experimented with, while inspecting the results interactively, since the functions are dynamically compiled at runtime. 3) Titanbrowse includes visualization tools, integrated to the database interface, so that results can be immediately inspected. These tools were built using IDL's standard library functions for the graphical interface and the cartographic projections. Figure 1 shows a screenshot of the current interface. 4) The creation of the functions of interest to make queries and visualize data can make use of the extensive built-in IDL library, with many functions common to scientific processing, but not usually found in database systems. For instance, the query or the visualization might use a function that calculates the area of an absorption band in the spectrum, or spherical geometry functions, or some arbitrary user-defined spectral indicator (such as a derived from Principal Component Analysis (PCA), integral transforms, or functions derived from theoretical models).

Results: Among other uses, this system has allowed us to discover the first tropical lakes on Titan [2]: Cassini observations had long before shown that Titan has large methane lakes on its polar regions [3]. Despite considerable community interest in searching for them in the tropical regions — where the Huygens probe landed on a dry lake bed — none had been found, until we used titanbrowse to search for them. Experimenting with functions to query the whole database, we were able to select those where the spectra indicated the presence of a lake. This revealed that, out of the millions of spectra in the database, a few dozen, all of a small region in the tropics, were consistent with the surface being covered in liquid. The data used in this study had been public for years, but since inspecting all the spectra was not feasible without a tool like titanbrowse, the lakes had remained undetected.

Current development: We are working on an online accessible version of titanbrowse. This will remove the users' need to download and install software and data. Users will be able to perform complex queries with integrated visualization using only a Java client, accessible through a web browser. The server will use IDL to access the data and process the queries, communicating the results to the Java server through a Java bridge. This demonstration server will be deployed on an Amazon Web Services server, so that it can be easily reconfigured, redeployed or scaled as needed, with a very low cost for the development and demonstration stages.

References:

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Additional Information: More information about titanbrowse, including, when available, its online implementation, can be found at

http://ppenteado.net/titanbrowse

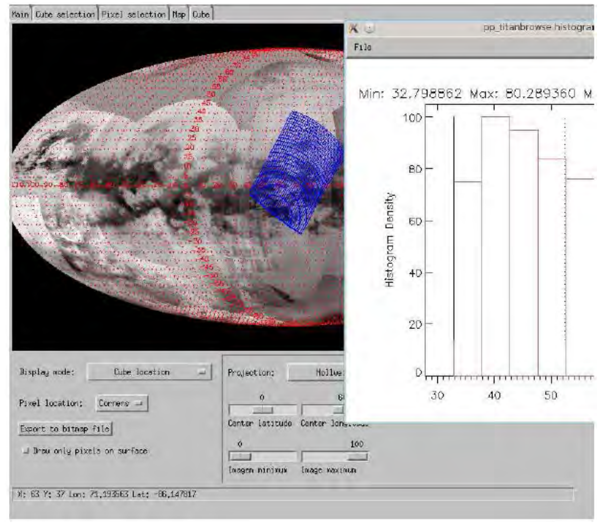

Figure 1: Example of the current titanbrowse graphical interface. The visualization on the left is an interactive map widget, in this case showing the location of the spectra currently selected by a query (pixel edges drawn as blue lines over the grayscale map). The visualization partly shown on the right side is a histogram widget, showing the result from evaluating a user-defined function, for each selected spectrum. This assists the user when defining queries, to determine adequate ranges of values, and when exploring data, looking for clusters or outliers. The histogram and the map are drawn automatically, inside the user interface, without requiring downloads. Use of these two visualizations of query results and function evaluations is essentially the method we used to discover the first tropical lakes on Titan [2].

DATA FROM THE LUNAR RECONNAISSANCE ORBITER (LRO): DATA PRODUCTS, TOOLS, AND COMMUNITY USE. N. E. Petro, J. W. Keller, and A. P. Morusiewicz, NASA Goddard Space Flight Center, Greenbelt, MD, 20771 (Noah.E.Petro@nasa.gov).

Introduction: LRO, with a compliment of seven instruments, was launched to the Moon on June 19, 2009. Since entering orbit, over 600 Tb of data has been deposited into NASA's PDS by the instrument teams. With a cadence of deliveries occurring every three months, the LRO holdings have evolved relatively rapidly with new data products and tools being generated with nearly each delivery. This data volume contains a range of products, including higher-level maps, mosaics, and derived products.

The PDS has made available the Lunar Orbital Data Explorer [1], a map-based tool to search for finding and downloading PDS science data of LRO as well as other recent lunar missions. In addition to the PDS holdings, several of the LRO instrument teams have additional products and tools available on their websites (Table 1).

Higher Level Data Products: Several global map products have recently been added to the PDS, here we highlight recent products. The Mini-RF team has assembled a global mosaic of their monostatic measurements [2]. For the first time we have global radar data for the Moon, data that clearly shows variations in rock abundance and surface texture over the entire lunar surface (Figure 1).

The LROC team regularly adds new products to the PDS via the team webpage (Table 1), including shape files, global mosaics, NAC-derived DEM's, and NAC mosaics of selected targets. Recently the LROC team has made available a number of anaglyphs (Figure 2) showcasing the ability of the LRO spacecraft and the LROC team to precisely target the NACs and the excellent registration of the camera system.

The LAMP team has a number of polar products available, including FUV ratio maps of both poles (Figure 3). These following maps are available at a resolution of 240 meters per pixel; Lyman-α (119.57–125.57 nm), Long (130–190 nm), On-band (130–155 nm), Off-band (155–190 nm), H_2O Absorption Feature Depth Maps made by a Ratio map of on/off band.

The LOLA team has prepared a number of map products and special polar products available from their PDS node (Table 1). These include DEM's at range of resolutions from 4 to 1024 pixels per degree and global LOLA-derived roughness (Figure 4) and slope maps at 16 pixels per degree. Special products, polar illumination, sky view, and solar visibility maps are available at 240 meters per pixel.

The Diviner team has multiple global derived products, including polar maximum and minimum temperatures, and from 60º North to 60º South at 32 and 128 pixels per degree, rock abundance, band center of the Christiansen Feature, and surface temperature.

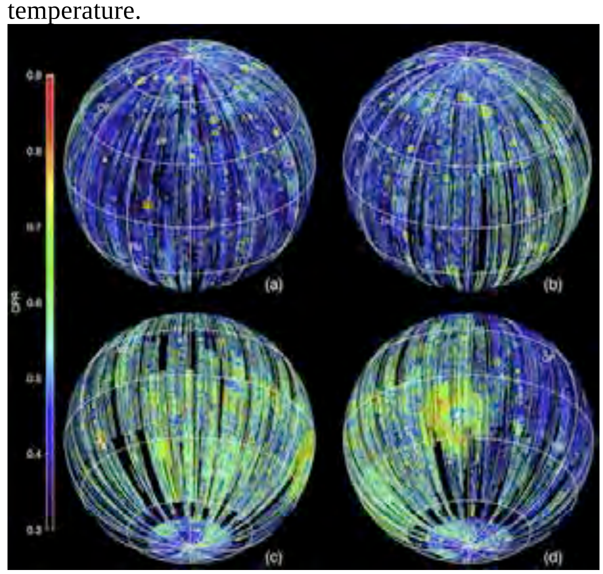

Figure 1. Mini-RF global mosaic of the Circular Polarization Ratio (CPR), one of the number of Mini-RF mosaic products now available online [1-3].

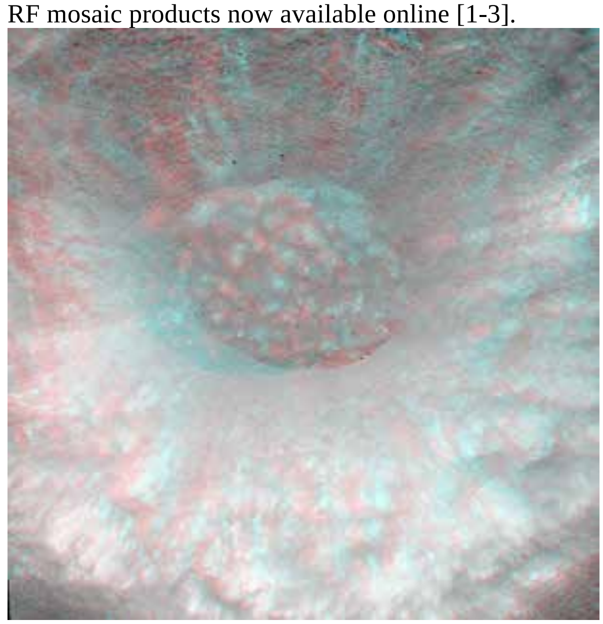

Figure 2. Red-Blue anaglyph of an 8 km diameter crater near Jenner crater. The LROC team has made a number of anaglyphs available on their website (Table 1).

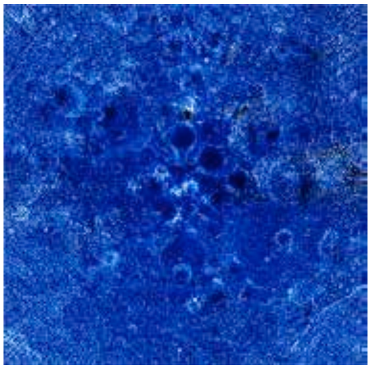

Figure 3. LAMP generated Lyman-**α** map of the lunar South Pole [3]. LRO has focused on volatiles at the South Pole since arriving at the Moon 5+ years ago.

Table 1. LRO team websites

LRO Project	lunar.gsfc.nasa.gov
Outreach	lunar.gsfc.nasa.gov/education.html
CRaTER	crater.sr.unh.edu
Diviner	diviner.ucla.edu
LAMP	boulder.swri.edu/lamp/
LEND	l503.iki.rssi.ru/LEND-en.html
LOLA	lunar.gsfc.nasa.gov/lola/ imbrium.mit.edu
LROC	lroc.sese.asu.edu
Mini-RF	nasa.gov/mission_pages/Mini-RF/main/index.html

Table 2. Web-based tools for working with LRO data.

Name	URL	Description
PDS Orbital Data Explorer	ode.rsl.wustl.edu/moon	PDS generated tool for downloading data from LRO and other lunar missions/instruments.
Quickmap	target.lroc.asu.edu/q3/	LROC created tool for displaying LROC images and products, and overlaying data from other instruments
Lunaserv	webmap.lroc.asu.edu/lunaserv.html	LROC created tool for projecting lunar data and accurate projection of global data.
LRO Data Users Workshop Archive	lunar.gsfc.nasa.gov/datausersworkshop.html	Presentations from the LRO teams on their datasets.

LRO Data Tools: A number of web-based tools are available that enable viewing, accessing, and interacting with LRO data (Table 2). These tools allow for users to find data over areas of interest, view higher-level map projected data products, and make cursory measurements (e.g., distance, elevation, spectral measurements). While these online tools do not replace other data analysis or image projecting software (i.e., ISIS, ENVI, MATLAB) they do facilitate finding the appropriate files.

Figure 4. LOLA generated roughness map [4] at 16 pixels per degree centered over the Western Limb (-90º Longitude) over an LRO WAC base image.

Use of LRO Data: The regular updating of LRO data guarantees a nearly constant supply of new data for the community to use. Announcements of new LRO Data are made via the Lunar-L listserve and the PDS website [3].

The LRO Project has begun holding a series of data users workshops with the goal of helping the community work with the large volume of LRO data. Prior to the 2015 LPSC each instrument team presented on the availability of data products as well as available tools for use by the community. Presentations given at the workshops are archived at the LRO website [5].

During the most recent LRO Senior Review the large number of scientific publications by the community that were published outside of the LRO instrument teams was deemed to be of high merit, and illustrated the usefulness and usability of LRO data. We encourage use of LRO data by the community, questions regarding the access and use of LRO data can be directed to the authors of this abstract.

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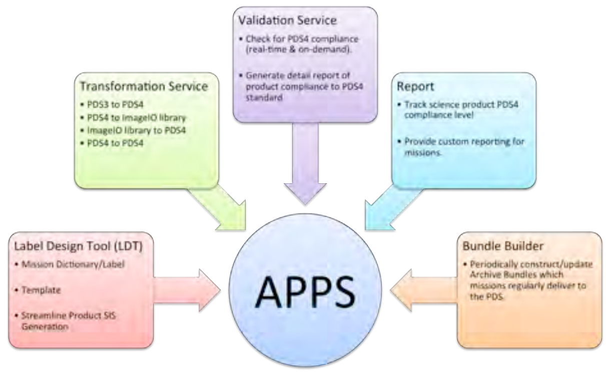
AMMOS-PDS Pipeline Service (APPS) – A Data Archive Pipeline for Mission Operations. C. Radulescu[1], S. R. Levoe[2], S. S. Algermissen[3], E. D. Rye[4], S. H. Hardman[5], J. S. Hughes[6], M. D. Cayanan[7], E. M. Sayfi[8], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Costin.Radulescu@jpl.nasa.gov, [2]same, Steven.R.Levoe@jpl.nasa.gov, [3]same, Stirling.S.Algermissen@jpl.nasa.gov, [4]same, Elizabeth.D.Rye@jpl.nasa.gov, [5]same, Sean.H.Hardman@jpl.nasa.gov, [6]same, John.S.Hughes@jpl.nasa.gov, [7]same, Michael.D.Cayanan@jpl.nasa.gov, [8]same, Elias.M.Sayfi@jpl.nasa.gov.

Introduction: The AMMOS-PDS Pipeline Service (APPS) [1][4] is a multi-mission science data (instrument data + metadata/label) transformation service, which connects product generation pipelines and the PDS [2] archive, therefore streamlining the delivery of science data to the PDS. The APPS pipeline is designed to run in parallel with a science data generation system, and ensure early data compliance to PDS4 Standards [3]. APPS was developed as a partnership between PDS and the AMMOS aiming to integrate the existing PDS4 tools and standards, and infuse them into the missions early, from concept to product delivery into PDS archive(s).

APPS consists of five major components:

- Label Design Tool (LDT) – create mission labels, and generate SIS documents.
- Transformation – Velocity-based product transformation.
- Validation – PDS validation (VTool).
- Reporting – PDS4 compliance reporting.
- Bundle Builder – PDS4 bundle creation using BPMN [5].

The presentation will describe in detail each component and its use case(s).



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[3]http://pds.jpl.nasa.gov/pds4

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[5] Object Management Group (OMG) Business Process Model and Notation (BPMN) http://www.bpmn.org/

PDS4 BUNDLE CREATION GOVERNANCE USING BPMN. C. Radulescu[1], S. R. Levoe[2], S. S. Algermissen[3], E. D. Rye[4], S. H. Hardman[5], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, Costin.Radulescu@jpl.nasa.gov, [2]same, Steven.R.Levoe@jpl.nasa.gov, [3]same, Stirling.S.Algermissen@jpl.nasa.gov, [4]same, Elizabeth.D.Rye@jpl.nasa.gov, [5]same, Sean.H.Hardman@jpl.nasa.gov.

Introduction: PDS4 [1] archives (a.k.a. "bundles") are collections of data, documents, and other supplementary information created by a data provider. Typical archives may include thousands of files, and therefore a certain organization is required to ensure proper long-term storage and retrieval. The AMMOS-PDS Pipeline Service (APPS) [2][3] provides a Bundle Builder tool, which governs the process of creating, and ultimately generates, PDS4 bundles incrementally, as science products are being generated. The process of generating bundles is formally defined using the Business Process Model and Notation (BPMN) 2.0 Standard [4], and executed on a business process engine pipeline.

The poster will show in more detail the BPMN flows used to describe the bundle creation processes, and how they are expected to generate an actual PDS4 bundle.

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[4] Object Management Group (OMG) Business Process Model and Notation (BPMN) http://www.bpmn.org/

An Overview of PDS4 Archival File Formats. Anne. C. Raugh[1] and John S. Hughes[2], [1]University of Maryland (Department of Astronomy, University of Maryalnd, College Park, MD 20742-2421), [2]Jet Propulsion Laboratory (4800 Oak Grove Drive, Pasadena, CA 91011).

Introduction: The Planetary Data System (PDS) has released the fourth version of its archival data standards. This version is a complete, ground-up redesign based on over two decades if institutional experience archiving observations from spacecraft, landers, ground-based observatories, and labs. We present an overview of the PDS archival formats, their derivation, and the rationale behind the archival format constraints and requirements.

PDS ARCHIVE OF DAWN FRAMING CAMERA VESTA GLOBAL MOSAICS. Th. Roatsch[1], E. Kersten[1], K.-D. Matz[1], F. Preusker[1], F. Scholten[1], S. Elgner[1], S. E. Schroeder[1], R. Jaumann[1], C. A. Raymond[2], and C. T. Russell[3], [1]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany, Thomas.Roatsch@dlr.de, [2]JetPropulsion Laboratory, California Institute of Technology, Pasadena, CA, [3]Institute of Geophysics, UCLA, Los Angeles, CA.

Introduction: The Dawn mission mapped the surface of the asteroid 4 Vesta over a period of nearly ten months at altitudes below ~700 km [1]. Imaging data from the Dawn Framing Camera [2] were collected in three primary mapping phases: High Altitude Mapping Orbit One (HAMO-1, September 29 - October 31, 2011) and Two (HAMO-2, June 24 - July 24, 2012) near 700 km altitude and the Low Altitude Mapping Orbit (LAMO, December 15, 2011 - April 30, 2012) near 210 km altitude. During the two HAMO campaigns, the surface of Vesta was nearly completely mapped in the clear plus seven band-pass filters.

Data Archive: Global mosaics created from the HAMO images [3] in each of these filters have been generated and archived with NASA's Planetary Data System (PDS). Mosaics with 70m/pixel resolution are provided in both cylindrical and polar stereographic projections (Fig. 1) using VICAR (Video Image Communication and Retrieval) format and attached PDS3 labels.

In addition, a "Clementine" color ratio mosaic (Fig. 2) was produced using HAMO images from filter numbers three, four, and eight [5,6]. There was insufficient downlink bandwidth during the LAMO campaign to map Vesta using all color filters. Some images were acquired in filters two, three, and four but not enough were obtained to be able to generate global mosaics.

Clear filter coverage of more than 80% of the surface was achieved in LAMO and these images were used to produce global mosaics with 20m/pixel resolution [4]. These mosaics are also archived with the PDS.

Dawn is currently approaching 1 Ceres and will map that body using a strategy similar to the one used at Vesta. There will be global coverage in all eight filters in a single HAMO campaign (August - October, 2015) at about 1500 km altitude and clear imaging only in a LAMO at about 400 km altitude (December 2015 - ???). The LAMO mapping will end when the hydrazine used to orient the spacecraft is exhausted.

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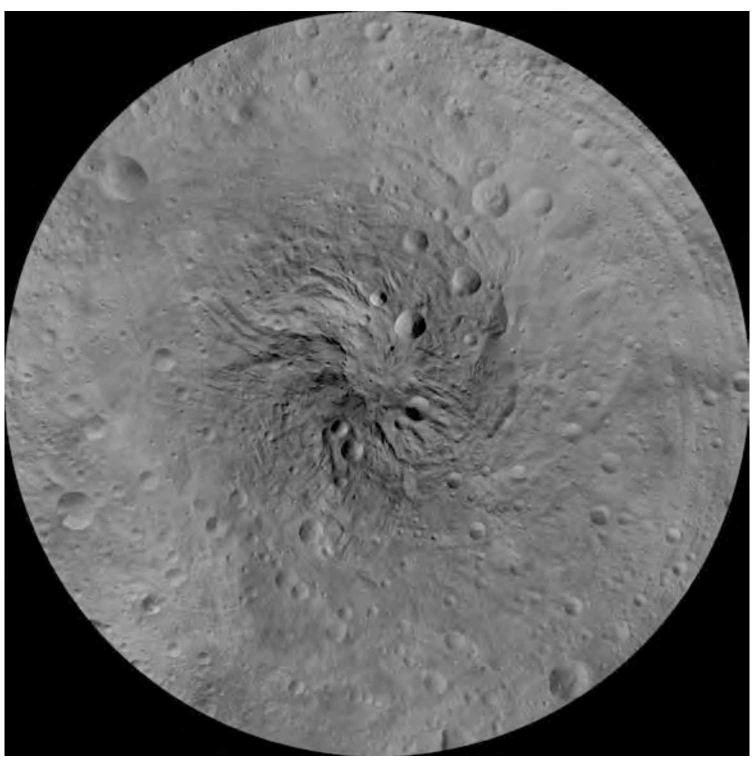

Fig. 1: Polar stereographic projection of Vesta's southern hemisphere from HAMO-1 images.

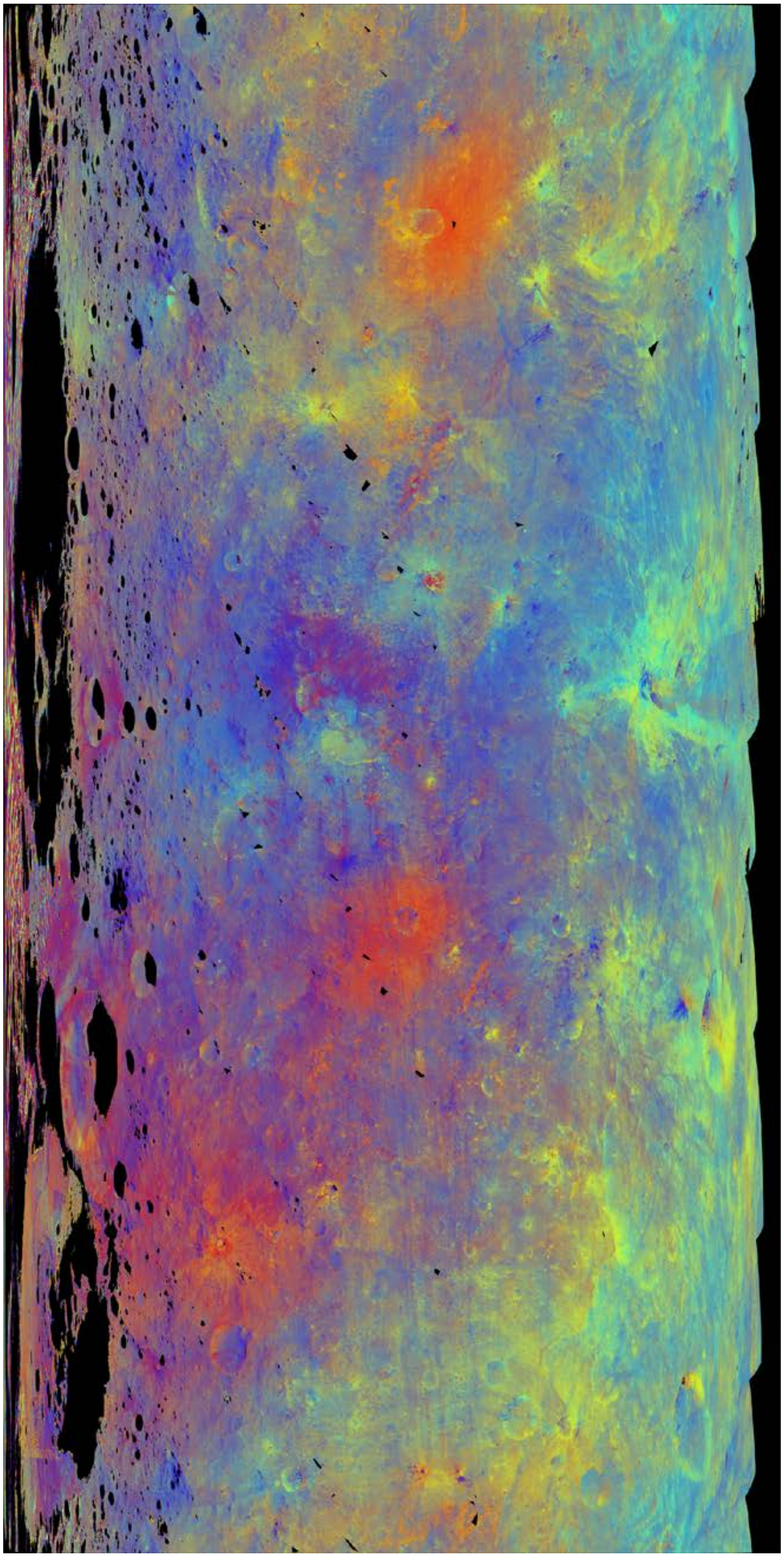

Fig. 2: Global "Clementine" color ratio of Vesta, red=750 nm/440 nm, green=750 nm/920 nm, blue=440 nm/750 nm.

LACE: A WEB-BASED, STRUCTURED EDITOR FOR PDS METADATA. M. Rose[1], R. Keller[2], and P. Sarram[3], [1]Lockheed Martin IS&GS, NASA Ames Research Center, Mark.Rose@nasa.gov, [2]NASA Ames Research Center, rich.keller@nasa.gov, [3]Pegah Sarram, pegahsarram@gmail.com.

Introduction: Many newer metadata standards are XML-based[1], including the PDS4 standard for the Planetary Data System (PDS)[2]. PDS4 metadata and data formats are required for all new mission data and analyses to be published within the PDS archive. At the same time, however, many scientists are not familiar with XML as a language for data modeling, nor are they familiar with tools for working with XML. Further, because of the relatively dense and verbose textual structure of XML, metadata written in XML is more difficult to create and read than prior textual metadata formats.

For these reasons, we have created LACE, an editor for PDS metadata that hides the complexity of XML from the user. Instead, the editor interface presents the user with familiar HTML forms and fields to fill in. At the same time, the metadata values are checked against schema restrictions in real-time to continuously show the areas of the metadata that still need attention. At any time the user can export the resultant metadata as a fully-formed, valid XML document. Working with LACE, it is not possible for users to create invalid PDS4 XML documents.

Schema-driven user interface: Although LACE was originally conceived as an editor for PDS4 metadata intended for the PDS, it is XML schema-driven: LACE dynamically adjusts its user interface to match the XML schema for the metadata standard[3]. In addition, it uses additional validation rules encoded as Schematron scripts, if provided[4]. LACE has been tested with other metadata standards such as SPASE from the Heliophysics community[5]. Users can also supply their own schema or Schematron, if desired. Thus, LACE functions as a general-purpose XML editor, and is not restricted to work with PDS4 metadata.

Integrated documentation: LACE automatically incorporates any documentation information from the XML schema(s) into the user interface, making the documentation available below the form fields for the affected XML element or attribute upon user request. In addition, LACE shows additional constraints specified in the schema, such as enumeration values or required patterns. Enumeration values are also available as drop downs on any field that requires a value from the enumeration. LACE will also display any customized error messages provided by Schematron rules.

Cloud-based collaboration: The LACE editor is cloud-based, that is, it runs entirely within a web browser, storing data remotely on a central server. This allows use of LACE from any modern browser without installation of specialized software. In addition, this format will allow the development of collaborative features such as those seen in enterprise-level, cloud-based applications.

Support for best practices: Since LACE stores the edited XML documents on the cloud-based server, it can reformat the documents when downloading them to the user. This allows LACE to conform to best practices within the community for which the metadata is being prepared. At this time LACE supports the practices of the PDS4 standard for the PDS archive, but it has been created in such a way as to facilitate use with other standards in the future.

Good usability: Development of LACE was accompanied by extensive user testing of the interface. Users have found the tool very easy to pick up and use with minimal instruction. It was the primary tool used by the data archive designer on the OSIRIS-REx mission for designing PDS4 label templates. Users have indicated that they found the interface intuitive and the documentation features helpful.

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How Long Is that Polygon?: A Centerline Algorithm E. I. Schaefer[1] and A. S. McEwen[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 USA (schaefer@lpl.arizona.edu).

Introduction: In planetary science, we frequently encounter geomorphic features that are polygons in planform: channels, valleys, ripples, yardangs, etc. We often quantify these features with "lengths" and "widths", yet neither of these measurements is straightforward for any but the simplest polygons.

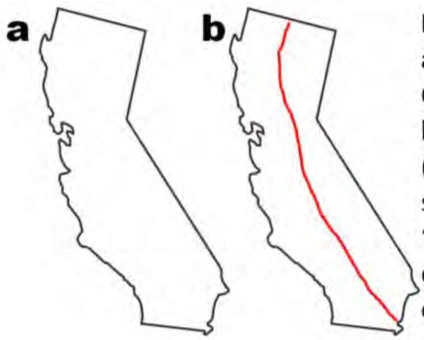

Fig. 1: **a**) Outline of California. **b**) Same as (a), with schematic "centerline" drawn by eye.

As an illustrative example, consider the outline of the state of California [**Fig. 1a**]. The human eye can easily recognize that this shape is elongate in approximately the NNW direction, but several questions immediately arise:

- Which is a better measurement of length: the simpler and shorter eastern border? the effectively fractal western coastline? neither?
- How can one measure the width of California, whether overall or at any point along its length?
- How can any measurement of length or width (or sinuosity, etc.) be reproducible if these measurements are fundamentally in the eye of the beholder?

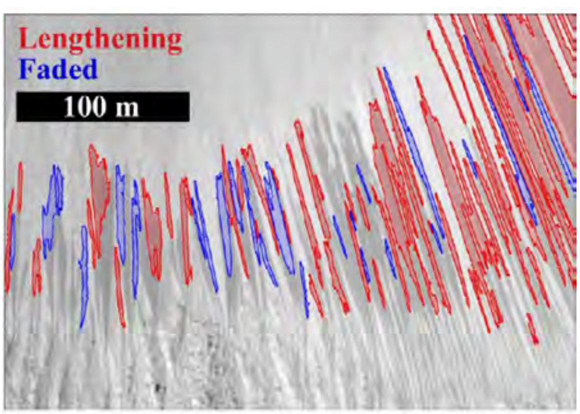

Fig. 2: automated classification [2] of RSL growth and fading regions relative to earlier HiRISE [3] image (not shown)

In the current era of abundant remotely sensed data and automated classification, yet another question arises:

- How can these and related measurements be made efficiently, preferably with a quantifiable error?

For example, the outlines of thousands of rivers on Earth [1] or recurring slope lineae (RSL) on Mars [2; **Fig. 2**] can be automatically mapped across images spanning years of changes, but this effectively leaves the scientist with only a measurement for area when a host of other measurements [4] would be useful:

- length and width
- the topology of these networks
- sinuosity
- changes over time and space for each of the above quantities
- the longitudinal topographic profile

Fortunately, the answer to each of the aforementioned questions is the same: an objective, automatically derived "centerline"—a curvilinear axis that is everywhere parallel to the length of the polygon [**Fig. 1b**]. Here, we describe our implementation of an algorithm to derive such a centerline for any polygon.

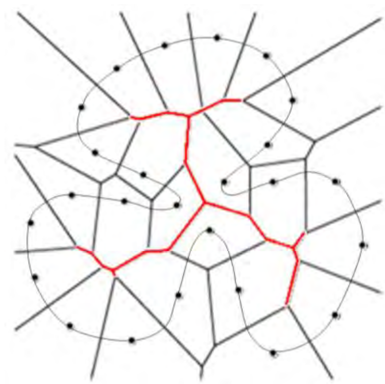

Fig. 3: Each Voronoi cell (black lines) is that region closer to one sample point (black dot) than to any other. The medial axis is colored red. [6]

Methods: [5] describe a very fast algorithm for converting a polygon to a linear representation. Called the medial axis transform (MAT), it involves dense sampling of a polygon's boundaries followed by Voronoi (Thiessen) analysis of these points and spatial filtering to isolate those facets of Voronoi cells that are wholly enclosed by the polygon [**Fig. 3**]. Unlike its predecessors, MAT's Voronoi analysis is point-based rather than line-segment-based, making it very efficient, yet it can be rigorously shown to converge on the true mathematical "skeleton" (a topological concept closely related to the centerline) [5].

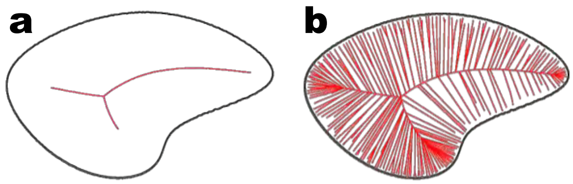

Fig. 4: Medial axes of (a) a smooth polygon and (b) the same polygon with short wavelength noise. [6]

Nonetheless, MAT has two key weaknesses.

- MAT is very unstable to noise [6]. For example, short wavelength undulation in a polygon boundary results in a very "hairy" skeleton [**Fig. 4**].
- MAT cannot reproduce the skeleton/centerline at the ends of an elongate polygon [3].

The latter issue is especially problematic if only a short portion of a elongate polygon, such as a valley, is in the field of view, or if length changes are a major focus of the study, such as for RSL [2,4].

We overcome the "hairy" skeleton problem by adapting the pruning method described by [6] and extending their pruning criteria. Similar pruning is also used to remove the edge effects of the MAT. We then use a novel bisection algorithm to reconstruct the centerline in these terminal regions.

When complete, our algorithm will have broad functionality, including:

- able to handle polygons with and without holes
- support for tuning how rounded the turns in the centerline are
- multiple options for isolating the "backbone" of a skeleton (for example, the main trunk in a map of tributaries)

Results: The algorithm is still in development, but nearing completion. Example output from the current code demonstrates the generality of the algorithm and the success of its novel pruning and centerline reconstruction components [**Fig. 5**]. The algorithm is also highly optimized:

- uses the Qhull library for Voronoi analysis
- leverages spatial indexing rather than geometric calculations wherever possible
- uses a custom geometric library specifically designed for performance

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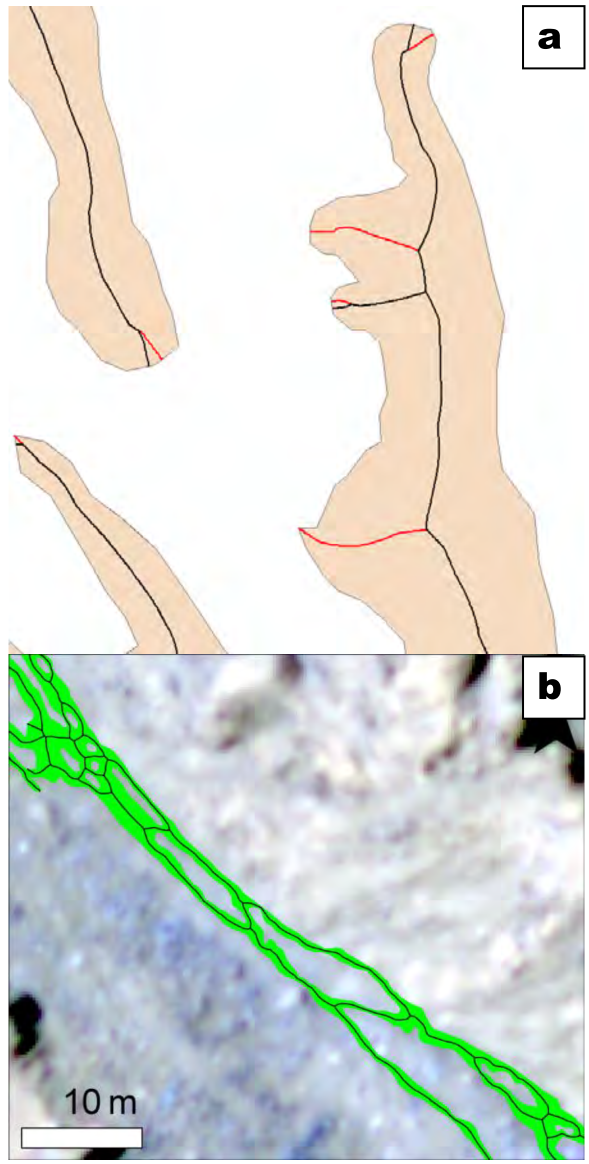


Fig. 5: (a) Centerlines (one black, the other red and beneath) for a test polygon, demonstrating how user-specified parameters affect the results. (b) A complex RSL polygon, as mapped by [4], and its calculated centerline.

Read and Browse Tools for PDS4 Data for IDL Users E.J. Shaya[1], [1]Astronomy Dept., University of Maryland, eshaya@umd.edu.

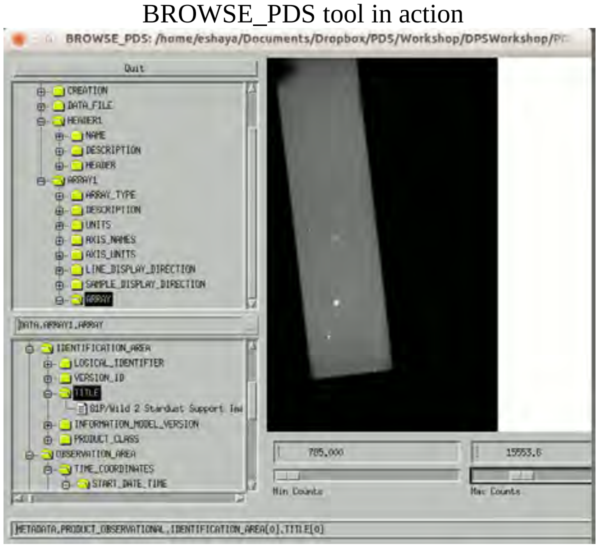
Abstract: Staff at the Small Bodies Node are developing tools in the IDL environment to read and browse PDS4 formatted data. The tools include **read_pds** which extracts relevant information on the data structures and their formats from the PDS4 XML document, and then reads all described data into an IDL structure. A key dependency of this procedure is our utility function **read_xml** which can read an arbitrary XML document into an IDL data structure.

The **browse_pds** tool depends on **read_pds** to read in all of the data of a PDS4 dataset and then opens a widget for browsing by mouse clicks. It allows users to quickly search/browse through the tree-structures of both the metadata and the data, view images and tables in a quick-browse graphics window, and it outputs any branch of the data that the user selects.

For users with IDL Version 8.3 and above, we have written another version of these tools which returns IDL Orderedhashes rather than IDL Structures.

A website at U. of MD links to descriptions and usages for each routine and a tar file holds all required procedures other than those in the Godddard Astronomy Library and built in procedures.
http://pdssbn.astro.umd.edu/tools/tools_readPDS.shtml

BROWSE_PDS tool in action



THE CHALLENGES OF STANDARDIZED PLANETARY GEOLOGIC MAPPING. J. A. Skinner, Jr., Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ, 86001 (jskinner@usgs.gov).

Introduction: Geologic maps provide the contextual framework for understanding the formative histories of planets. These are based on consistently documentable characteristics of rock and sediment units as well as their spatial and temporal associations with one another. The geologic mapping concept – that a planetary surface can be uniquely differentiated into three-dimensional bodies of lithic material – is relatively straightforward. However, strategies and tactics differ depending on the body of interest, the scale of the map, and the background of the mapper. The observations provided in standardized geologic maps critically outnumber the interpretations, providing an objective context wherein map users are encouraged to make their own interpretations. Moreover, this standardized context allows for researchers to rely on the mapping process and product and to "speak the same language" when discussing differing terrains.

Planetary geologic mapping – similar to most planetary science disciplines – has undergone an important positive transformation during the past ~15 years due to the exploding volume, variable type, and diverse spatial resolution of data returned from orbiting and landed spacecraft. Other significant contributors to this transformation include increased availability (and lowered cost) of various programs that support data integration and analysis, required production of geologic maps in geographic information system (GIS) format, and a gradual trend away from projects that focus almost exclusively on the production of a geologic map (i.e., "mapping for the sake of mapping"). Although the renaissance of planetary geologic mapping has resulted in more informative and unique cartographic products, it has been met with its own set of challenges. This abstract examines some of these challenges and offers recommendations to overcome them in order to ensure the continued production of benchmark, contextual geologic maps of planetary bodies.

Background: The U.S. Geological Survey's (USGS) Astrogeology Science Center has historically provided coordination and guidance for NASA's planetary geologic mapping program sponsored by NASA's Planetary Geology and Geophysics program. Under the auspices of NASA's Planetary Cartography and Geologic Mapping Working Group and its Geologic Mapping Subcommittee, USGS provides the community with (1) assistance with geologic mapping program, (2) collective coordination of all active maps, (3) generation of base maps and databases for funded researchers, (4) development of (and guidance for) achieving cartographic standards, (5) editorial support in map reviews and revisions, and (6) preparation for and final printing of maps in the USGS Scientific Investigations Map (SIM) series. It should be made clear that the USGS is not equivalent to – but a part of – the broader cartographic research community. The USGS is directed by the science community and NASA to facilitate the standardization and production of geologic maps. In short, we create and maintain the infrastructure that enables scientific investigation. The USGS survives on critical input from the scientific community and should be viewed as a resource that evolves in response to strategic needs on the 5+ year timeframe.

Challenge #1 – Map Specifications: Researchers who perform systematic geologic mapping on non-terrestrial bodies as part of a scientific investigation now have an increased responsibility (relative to past decades) to carefully select the most appropriate data sets to answer the outstanding scientific problem at hand. This poses an interesting question to be answered by proposers, review panels, and program managers: What are the "correct" approaches, rationales, and specifications for the successful completion of a standardized geologic map?

To make an effective case for competitive selection, proposers who opt to produce a USGS SIM series geologic map must summarize (and succinctly justify) critical specifics regarding the map product, including (1) scientific relevance by delineating limitations of past-published maps, (2) selected (primary) base and (secondary) supplemental data sets that are required for effective mapping, (3) latitude and longitude boundaries of the map region, and (4) map scale and projection. Map base, scale, and projection are particularly important for evaluating whether the project can be completed as proposed and whether the map can be feasibly supported by USGS and NASA. For example, mappers must be aware of incompatibilities of image resolution and map scale, as not all data sets are relevant at all map scales (*e.g.*, HiRISE images cannot feasibly support unit identification and delineation at 1:1,000,000 scale).

Challenge #2 – Community Awareness: A critical part of the NASA-supported and USGS run planetary geologic mapping program is properly conveying map information to community researchers. It is not helpful to USGS, NASA, the scientific community or public if high-level data products are not advertised and pushed into the community for use. The challenge is ensuring that the community is continuously aware of the process and products of planetary maps. Understanding the process helps the community understand the timeframe as well as the efforts that support the work. It helps to have the community aware so that they can obtain and use the products and evaluate them on review panel. Use of geologic maps can be evaluated by various quantities, including citation statistics, web requests, and shipping details. It is the totality of these quantities that most appropriately track the health of the planetary geologic mapping community and help to ensure that NASA is getting a sufficient return on its investment.

Challenge #3 – International Collaboration: The process and product of geologic mapping is approached by institutions in multiple countries around the world. However, there are no other institutions that produce standardized geologic maps of planetary surfaces. The NASA-USGS relationship maintained over the past four decades has resulted in cartographic products, particularly planetary geologic maps, as the international benchmark standard. The challenge is that international contributors do not have direct access to USGS publication opportunities despite a high level of understanding of and commitment to the mapping process. Though community standards for planetary geologic mapping are posted on USGS websites and are available to the national and international community for adoption and use, it is the process of technical review, coordination, cartographic standard, and objectivity that is the benchmark component of USGS products. Currently, non-NASA products geologic maps are published in peer-reviewed journal articles, which is a sufficient (and encouraged) venue for publishing topical study maps where interpretations outweigh the observations. However, the scientific community is losing out on elevating these contextual products, which undercuts community education about the value of the process and product.

Challenge #4 – Timeliness: There is a perception in the science community that the production of planetary geologic maps is lengthy (perhaps too lengthy), which in turn fosters a perception that these products are behind the times. This perception has embedded accuracies and inaccuracies and a particular challenge is disentwining these two in order to make sure the broader science community understands the timeliness and responsiveness of geologic maps. Timeliness starts with proposers understanding not only the requirements of the geologic mapping process and product but also budgeting accordingly for these requirements. Proposers must ensure that they have budgeted time to accommodate response to technical reviews, which often entail significant alteration of maps components. One challenge is that maps are often submitted near the end of the funding cycle, which leaves little time (or money) for the authors to integrate the required changes. Another element of timeliness to community needs is the ability to "expedite" the review and publication process when maps are considered by the community to be high priority. It should be realized, however, that the review and production process of standardized maps is – by definition – tedious and time consuming. Proposers (and program managers) can consider the time from submission for technical review to final printing to be at least 12 months if all players (reviews, authors, USGS coordinators, editors and cartographers) are responsive. Assistive measures for ensuring timely work flows include tutorials and workshops, map component templates, author and reviewer checklists, and active liaising between authors and USGS Publication Services Center (PSC). However, the best assistive measure is a clear understanding of (and dedication to) the mapping process, which includes technical review and production. Authors must remain engaged throughout.

Challenge #5 – Next Generation Mappers: Geologic mapping is an inherently integrative scientific endeavor, which makes it appealing to students. Though project management and the flurry of details related to map review and production should necessarily be handled by the author, the planetary mapping community needs to grasp that part of our responsibility in maintaining the health of the mapping program long term is seeding the community with young researchers who have an understanding of (and "knack" for) the geologic mapping process. Equivalent to other disciplines, standardized geologic mapping is a learned and skilled endeavor which must be developed and honed. The perception that "anyone can do geologic mapping" is not correct. A challenge is ensuring that geological mapping skills are maintained, if not enhanced, over the coming years so that the science community does not lose the personnel or product resource.

Acknowledgements: Community support for the coordination, review, and production of planetary geologic maps by the USGS is critically supported by NASA's Planetary Geology & Geophysics program.

PDS Imaging Node Atlas III and Faceted Navigation. A. Stanboli[1] and S. LaVoie[2], [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109), [2]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109).

Faceted navigation is a form of product search that has been utilized in the retail industry since the early 2000s.[1] Online shopping interfaces such as amazon.com and Google Shopping are leading examples of the use of faceted navigation. By allowing faceted navigation the user is able to apply or remove facet constraints in any order.[2] A facet is a distinct feature or aspect of a set of objects and a way in which a resource can be classified.[3] The PDS Imaging Node Atlas III utilizes faceted navigation, an interactive style of browsing datasets that allows users to filter a set of items by progressively selecting from only valid values of a faceted classification system. In the Atlas III facets are defined by the most commonly used search criteria for imaging datasets including but not limited to: mission name, instrument name, target, product type, lighting geometry meta-data (emission angle, incidence angle, phase angle), lat/lon meta-data, time constraints, etc. As the user applies a constraint the user will get immediate feedback with counts next to each facet listed. For example, when the user applies the constraint of mission name equals Cassini, the list of targets will be updated with counts next to each target listed. This takes away from the need for prior knowledge, a common complaint of previous users of search interfaces. Without the immediate feedback displaying how the data is distributed among facets, older systems required a user to guess what constraint they should apply next to narrow down the results. The user interface of the Atlas III has also been redesigned to follow the traditional layout of a faceted navigation interface. Traditionally faceted navigation interfaces display filters on the left of the screen and a grid of images to the right. In addition to the faceted approach, the Atlas III builds on the features of the previous Atlas including a map interface for the Saturnian moons, Earth's moon and Mars. The Atlas III also incorporates the use of the MGSS webification backend that makes use of the image transformation software developed by MGSS (MIPL) through javascript widgets.

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THE PLANETARY DATA SYSTEM GEOSCIENCES NODE DATA SERVICES. T. C. Stein[1], J. Wang[2], E. A. Guinness[3], [1]Department of Earth and Planetary Sciences, Washington University in St. Louis, 1 Brookings Drive, Campus Box 1169, St. Louis, Missouri, 63130, tstein@wustl.edu; [2]wang@wunder.wustl.edu; [3]guinness@wustl.edu.

Introduction: The Planetary Data System (PDS) Geosciences Nodes has developed two web based services for searching and downloading planetary geoscience data. The Orbital Data Explorer (ODE) (http://ode.rsl.wustl.edu) provides access to orbital data from Mars, the Moon, Mercury, and Venus. The Analyst's Notebook (AN) (http://an.rsl.wustl.edu) provides access to landed data sets. There are separate ANs for the active missions Mars Science Laboratory (MSL) and the Mars Exploration Rovers (MER) and for the past missions Phoenix Lander, LCROSS, and the Apollo surface missions. For both services the archives can be searched and data products can be downloaded individually through the web-interface or placed in a cart for later bulk download with FTP. Both services also provide access to documentation included in the archives.

Orbital Data Explorer (ODE): The ODE delivers the ability to search, display, and download PDS data from many orbital planetary missions to the terrestrial planets [1]. For a few data sets derived from instruments that collect point data along an orbit track, ODE provides a granular-level search. This tool allows a user to specify a set of search parameters whereby ODE will search each of the data products to extract the individual records that match the search criteria. The extracted data records are placed into custom data products that the user can download. Currently, ODE supports granular-level searches for the 595 million point MOLA PEDR (Precision Experiment Data Record) data set from MGS and the 6.5 billion point LOLA RDR (Reduced Data Record) and 213 billion point Diviner RDR data sets from LRO. ODE also provides a REST (Representational State Transfer) interface (http://oderest.rsl.wustl.edu) for external users that want to access the ODE metadata and data products without using the ODE web interface. The REST interface allows external users to develop domain-specific tools and interfaces to the data products and metadata within ODE.

Data searching and retrieval. ODEs allow users to search for science data products via form-based or map-based interfaces. Users can make a form-based query by setting parameters of mission, instrument, product type, coverage, location, time, observation angles, and product ID with the form-based Data Product Search interface. Users can also make queries on the Map Search interface with the Select Products By Area tool or by setting parameters in the Map Display Controls panel. ODE supports queries on both single and multiple missions, or searches among single and multiple instruments. Search results are shown in a table or on a map.

Data representation. Details of search results are shown in a table with a set of functions to select more product information such as browse, metadata, PDS label, or map context. The browse version of image-oriented products provides an overview of the product to help users make downloading decisions. In addition, users may view the products with the footprints or bounding boxes plotted on a base map.

Map display. The ODE web map includes both footprint coverage and base map layers. The footprint coverage maps display the location of data products. Each map layer includes all of the product footprints per instrument product type. Each footprint shows an individual product's surface area coverage. The base map layers provide context background. The footprint maps are overlaid on a number of base maps. The transparency of each map layer can be adjusted in order to provide for combined presentation of layers. Some footprint maps, such as CRISM TRDR, DIVINER and LROC are slow to display due to the large number of product footprints rendered on the map layer. These layers are highlighted with an icon indicating their expected performance.

The ODE web map interface was built based on the ESRI® ArcGIS Server and ArcGIS JavaScript API. Basic functions include map display, pan, zoom in/out, and navigation.

Data Download. Multiple options are provided for acquiring data products from ODE. Users can select and order data products using a web-based "shopping cart" approach, or directly download individual files through the ODE interface.

Footprint coverage maps in KMZ and shapefile format. As mentioned, footprint coverage maps allow users to see what portion of a planetary surface is covered by the footprints of all products of a given product type of a given mission and instrument. ODEs generate product-type coverage KMZ files and shapefiles for further access of the product coverage data with Google Earth/Mars/Moon or other GIS tools. The coverage files include basic product information and links to product details in ODE to assist the user in acquiring product files through this method.

Coordinated observations. A coordinated observation is a planned observation involving multiple instruments at a given location and time. A coordinated observation search tool was developed specially for the MRO mission. It allows users to find and view related products from MRO HiRISE, CRISM, CTX, and MCS, as well as the Phoenix Lander data.

REST interface. ODE also provides a simple web-based REST interface to allow other groups to develop specialized or domain-specific interfaces to search for PDS products, obtain metadata about those products, and download the products through the URLs stored in ODE's metadata database. Additionally, the ODE REST V2.0 Beta interface also supports MOLA PEDR, LOLA RDR, DIVINER RDR, and Mercury MESSENGER MLA RDR granular-level queries. The query results are the same as the current ODE web-based granular query.

The Analyst's Notebook (AN): The AN service integrates data archives with observation planning and targeting information and documentation to allow the user to place individual data observations in the context of other observations and the reasons for acquiring the data, effectively playing back the mission [2].

Content: The ANs for the Mars missions contain the peer-reviewed, released archives for all science instruments. These notebooks are updated with each PDS data release. The data are supported by documentation that describe the data format and calibration. Other documents are included that provide insight into why particular observations were made along with overall mission strategy and science objectives.

Observation planning and targeting information is extracted from Mars mission science plans and presented in both timeline and list form. Effort has been made to link source commands with resulting data products, albeit with limits due to the absence of round trip data tracking.

Navigation: Data can be found using an interface with a searchable and sortable high-level summary of each sol (Mars day) activities. The primary method for accessing mission data and information is through the Sol Summary interface that links data, documentation, and image mosaics for individual sols or a small group of sols. A map interface provides a view of rover traverses on a base map that can be zoomed and scrolled through. The user can select any rover position in order to be linked to the data for that location.

Data holdings may be searched by time (sol, spacecraft clock time, and UTC date), location (rover-specific site and position), instrument, command sequence, product type, image eye and filter, and product ID. Sol documents may be searched by type, time, and filename. In addition, free text searches are supported. Results are displayed based on user settings, and searches can be bookmarked for later recall.

Context Mosaics: The PDS data archive for MSL includes mosaics generated by the science team from Navcam data. However, sometimes sequences of single frame images are acquired for the purpose of creating a mosaic without a formal data product being archived. For these cases, we have created mosaics from the single frame images to provide context, and have included them in the MSL AN.

Context mosaics, which are not calibrated science products, are created from Navcam, Mastcam and MAHLI images using Microsoft Image Composite Editor (ICE) software in either perspective or simple horizontal cylindrical projection. Navcam context mosaics are created by stitching radiometrically calibrated images and then applying a linear 2% stretch. Mastcam and MAHLI context mosaics use DRCL (radiometrically calibrated and linearized) products as sources. Projection information for the context mosaics is available in the EXIF (Exchangeable Image File Format) data that are part of the embedded JPG file header with each mosaic.

Tool Updates: Both the ODE and AN services are updated for active missions as new data are released by missions to the PDS, typically once every three months for a given mission. Additional data sets are added to ODE based on science community input. In the future, the Geosciences Node plans to create and maintain additional ANs for the InSight and Mars 2020 missions once they begin operations.

Future Development: An updated Map Search interface is currently under development for ODE with the goals of improving performance, usability, and the process of individual product display and download. Work continues to incorporate additional features in the AN, especially in the areas of related observations and visualization, as well as data transformation.

Feedback: A number of ODE and AN functions are based on previous user suggestions, and feedback continues to be sought. (User feedback should be submitted to geosci@wunder.wustl.edu or by using the online form.)

Acknowledgement: The Orbital Data Explorer and the Analyst's Notebook are developed through funding provided by the Planetary Data System Geosciences Node. Ongoing cooperation of the mission science and operations teams as well as the PDS Atmospheres, Imaging, and PPI Nodes is greatly appreciated.

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HIRISE DIGITAL TERRAIN MODELS: UPDATES AND ADVANCES S. Sutton[1], R. Heyd[1], A. Fennema[1], A. S. McEwen[1], R. L. Kirk[2], E. Howington-Kraus[2], A. Espinoza[1], and the HiRISE Team. [1]Lunar and Planetary Laboratory, University of Arizona, (1541 E. University Blvd. Tucson, AZ 85721 USA ssutton@pirl.lpl.arizona.edu), [2]U.S. Geological Survey Astrogeology Science Center (Flagstaff, Arizona, USA)

Introduction: The High Resolution Imaging Science Experiment (HiRISE) camera [1], operating on the Mars Reconnaissance Orbiter (MRO) [2] since 2006, has acquired over 4200 stereo pairs to date. Digital Terrain Models (DTMs) generated from HiRISE stereo pairs are regularly released to the Planetary Data System (PDS). As of April, 2015, 235 DTMs are available via the PDS, and also at http://hirise.lpl.arizona.edu/dtm. We present recent and upcoming updates and advances to the HiRISE DTM data set.

Stereo Targeting: HiRISE acquires stereo image pairs by rolling the spacecraft off-nadir for one or both images. Each image is acquired on different orbits. Stereo targeting procedures have been refined over the mission to minimize lighting differences between images. For targets that are susceptible to rapid surface changes (i.e. frost, aeolian changes, etc.), great effort is made to acquire each half of the stereo pair as close in time as possible. Imaging geometry considerations such as look angles and convergence angle are also optimized based on the target topography and the available observing opportunities.

Prioritization and Release Schedule: DTM requests are prioritized internally by the HiRISE team. The two primary producing instutions are the University of Arizona and the USGS Astrogeology Science Center Photogrammetry group. Requests are generally either for research or for landing site assessment. Research requests by HiRISE team members are given priority, followed by external requests if resources allow. Landing site DTMs are generally funded through other programs and are produced according to the schedule for that mission/program.

DTMs from other institutions. Many other instutions are now producing high quality HiRISE DTMs thanks to the well-documented training and tools made available to the community primarily through the Photogrammetry facility at the USGS Astrogeology Science Center in Flagstaff, Arizona [3]. The consistency of procedures and documentation makes it possible to PDS archive HiRISE DTMs produced at other institutions, provided they meet quality standards. Please email the corresponding author for details about what is required to archive HiRISE DTMs in the PDS.

Release to the PDS. Preparation of DTM and related files in standard PDS formats is done at the HiRISE Operations Center (HiROC) at the University of Arizona [4]. DTMs produced for research are typically released to the PDS one year from their completion. DTMs for landing site assessment are released sooner, as requested by those teams. DTMs produced externally and delivered for PDS release may be released on a schedule specified by the producing institution. Updates to the PDS catalog occur monthly, as new projects become available.

Updates to Preprocessing: The significant advancement to HiRISE image preprocessing for DTM production is jitter correction via the HiPrecision subsytem. Other improvements are being tested, such as frequency domain processing that removes subtle electronic noise. These image processing techniques have been shown to improve DTM quality, reducing artifacts and editing time.

HiPrecision. The HiPrecision processing subsytem at HiROC has two branches: HiRISE Jitter-Analyzed CK (HiJACK) and HiNoProj [5]. HiNoProj duplicates the standard preprocessing of HiRISE images for stereo analysis in that it runs the Integrated Software for Imagers and Spectrometers (ISIS) program *noproj* [6] on each CCD image strip to remove optical and camera distortions, placing them in a single mosaicked image in a non-map projected "ideal camera" space. The HiJACK branch performs the same geometric correction, while additionally removing distortions in the images due to spacecraft jitter [7]. The output of HiPrecision is essentially what is needed for the input to HiRISE stereo processing. Requests for these products are being accepted now via email to hidip@pirl.lpl.arizona.edu.

Noise removal. This procedure is currently in testing, but will be incorporated in the HiROC calibration pipeline. It removes subtle regular electronic noise by processing individual CCD channels in the frequency domain. This improves the success of the stereo matching algorithm by minimizing noise patterns that occur at 1 or 2 pixel spacing. This processing will benefit HiRISE image analysis in general.

Method: The primary method for creating HiRISE DTMs as discussed here is based on the ISIS 3/SOCET SET ™ (BAE Systems, Inc.) procedures developed by the USGS Astrogeology Photogrammetry group [8]. This method relies on pre- and post-processing in ISIS. HiRISE images are radiometrically and geometrically calibrated in ISIS. The images are bundle adjusted and triangulated to the Mars Orbiter Laser Altimeter (MOLA) [9] gridded and point data in SOCET SET. New tools are available to automate and improve the registration of HiRISE to MOLA, such as *pc_align* from Ames Stereo Pipeline [10], or *autoTriangulation* from the HiRISE team [11]. After an acceptable fit to MOLA is achieved, the source stereo images are orthorectified. Additional images of the scene may also be orthorectified to the same DTM. The output from SOCET SET is map projected and PDS mapping definitions and labels are applied by ISIS routines.

Accuracy and Precision: Horizontal precision is 1 or 2 m, depending on the summing mode of the source stereo images (25 cm or 50 cm pixel scale, respectively). Horizontal and vertical accuracy are determined by best fit to MOLA shot points. Due to the large difference between the spatial resolutions of these two data sets, absolute horizontal accuracy is only as good as that of MOLA. Vertical accuracy is reported in the README text file, when available. This is measured by the average and standard deviation of differences between the terrain model and the MOLA shot elevations. Vertical precision can be estimated with knowledge of the stereo images' pixel scale, the triangulation RMS error and the convergence angle between the stereo pair [12]. This value will be calculated and reported in the README file in future releases. Other factors can locally affect the quality and accuracy within a DTM, such as dusty or bland areas, jitter, image noise, or shadows [13]. The Figure of Merit (FOM) map is generated to classify the correlation values reported from SOCET SET into a product that provides the user a guide to the quality of the DTM at each post (**Fig. 1**).

Figure 1. FOM map showing areas where low stereo correlation led to interpolation artifacts (orange), good correlation (green), and manually edited areas (turquoise).

Products: The products released to the PDS are in two categories: Standard and Extras. The standard products are the DTM in a 32-bit raster format (.IMG) with an embedded label, and the orthoimages as 8-bit JPEG-2000 (.JP2) images with detached PDS labels (.LBL). Extras are reduced resolution browse images (.jpg) in annotated and non-annotated versions. Cartographic definitions match the HiRISE Reduced Data Records (RDRs) as much as possible to maintain consistency with the HiRISE catalog.

DTM. Terrain is extracted at 1 m or 2 m post, or grid spacing. In most cases, one stereo pair is used per DTM. Contiguous adjacent stereo pairs can be used to produce regional DTMs. However, in the PDS, each pair is released individually with its corresponding orthoimages. At this time, it is up to the end user to mosaic these products. The HiRISE team may make mosaicked products available in the future. Information about images used in a single solution is contained in the README file.

Orthoimages. Orthoimages are generated at the source pixel scale (25 cm or 50 cm) as well as at the corresponding DTM scale. Color orthoimages are also generated, when available (HiRISE has a narrow central swath of 3-band color in Near-IR, visible red and blue-green). Additional images acquired over a target can be orthorectified by tying them to the existing stereo pair for a DTM. This allows for highly accurate change detection studies to be performed.

Extras. Browse images of the DTM are produced as grayscale, shaded relief, and colorized altimetry. Browse versions of the orthoimages are also available. The FOM map is produced as a color-coded map draped over a shaded relief image (.JP2), with a separate legend. The README text file contains basic information about the project, as well as an explantion of the naming convention and possible artifacts.

Conclusion: HiRISE DTMs are valuable data or geologic research, landing site hazard assessment, and visualization. Although there have been many improvements and refinements to the procedures used to create them over the years, they are still difficult to generate, requiring a great deal of operator skill and computational resources. The HiRISE team strives to communicate information about these DTMs, and new tools available for their creation and analysis, to the community, to enhance the science return from these products.

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Improving the Discoverability and Availability of Sample Data and Imagery in NASA's Astromaterials Curation Digital Repository Using a New Common Architecture for Sample Databases. N. S. Todd[1] and C. Evans[2], [1]UTC Aerospace Systems/JETS Contract, NASA Johnson Space Center, Mail Code XI2, Houston, TX 77058 (email: nancy.s.todd@nasa.gov), [2]NASA Astromaterials Curation Office, NASA Johnson Space Center, Mail Code XI2, Houston, TX 77058.

Introduction: The Astromaterials Acquisition and Curation Office at NASA's Johnson Space Center (JSC) is the designated facility for curating all of NASA's extraterrestrial samples. The suite of collections includes the lunar samples from the Apollo missions, cosmic dust particles falling into the Earth's atmosphere, meteorites collected in Antarctica, comet and interstellar dust particles from the Stardust mission, asteroid particles from the Japanese Hayabusa mission, and solar wind atoms collected during the Genesis mission.

To support planetary science research on these samples, NASA's Astromaterials Curation Office hosts the Astromaterials Curation Digital Repository [http://curator.jsc.nasa.gov/], which provides descriptions of the missions and collections, and critical information about each individual sample.

Our office is implementing several informatics initiatives with the goal of better serving the planetary research community. One of these initiatives aims to increase the availability and discoverability of sample data and images through the use of a newly designed common architecture for Astromaterials Curation databases.

NASA's Astromaterials Curation Databases: The Astromaterials Curation Databases contain vital information about NASA's astromaterials collections. Data in these databases include complete documentation about the samples and their history including sample processing data and images, preliminary characterization data, JSC handling and storage, and allocation activities. These data holdings are continually updated with new samples, photos, and related documentation.

Limitations of existing databases. Despite the wealth of information collected in the databases, there were many obstacles to making these data available to the scientific community in a highly discoverable fashion. Each collection had its own separate database with its own technical implementation, which vastly differed between collections. This made it very difficult to find and present data as interaction between databases was problematic and data was often inconsistent between collections.

To address this problem and enhance searchability and access to the data, a multi-year effort was launched to pull individual collection databases into a common architecture and provide common functions to the PI community and the curatorial staff.

The Astromaterials Sample Tracking and Reporting Application (ASTRA) Framework: The newly designed common framework consolidates all common functionality into a services library that manages the access to data and standardizes the implementation of common processes for all collections. The following table shows the features and benefits of this application framework.

ASTRA Framework Features and Benefits

FEATURE	FUNCTION	BENEFITS
COMMON FRAMEWORK LIBRARY	Provides centralized common services that standardize the implementation of common processes in Curation. Provides notification services for key parts of the request and allocation process.	1. Simplified sample tracking operations. 2. Improved communication of status to Curators and PIs. 3. Improved high-level reporting. 4. Reduced rework on new collection database apps.
INDEPENDENT SERVICE MODULES TO ACCESS DATA	Encapsulates all data-related functionality independent from the user interface. Implemented with ColdFusion Server, a mature and stable application server that is well supported and updated frequently.	1. Data can be accessed and manipulated through a variety of user interfaces without affecting the data management logic. 2. Isolates the process logic and data access from frequently changing user interface technologies.

INDEPENDENT USER INTERFACES	Provides user access to all the functions needed to perform their jobs. Can be customized for each collection independently or use common custom components. Implemented using Adobe Flex, which can produce output in Flash, HTML5, JavaScript, and native iOS.	1. Isolates user interface from data services so it can access data using a variety of methods. 2. Can be changed more frequently without affecting the application logic and data access. 3. Uses a common code base that can generate content optimized for different platforms and environments.
ADMIN APPLICATION	Centralizes access to all common functionality from one location. Houses Curatorial Order administration, Tours management, Mail management, and User security management.	1. Provides single point of access to Curation applications. 2. Provides app administration functions to delegate app and user management responsibilities outside of IT department.
CENTRALIZED DATABASE FOR ALL CURATION COLLECTIONS	Maintains all sample data collected during the Curation process. Implemented using Microsoft SQL 2008 R2. Proposed upgrade to SQL 2012 Enterprise Server.	1. Ensures consistency and accuracy of data across all collections. 2. Easier to create audit and management reports that aggregate data from all collections. 3. Upgrade to Enterprise edition will allow real-time monitoring of server and a complete auditing solution that tracks every change to the data to ensure data integrity.
DOCUMENT AND PHOTO MANAGEMENT	Allows users to upload documents and photos and associate them to a specific sample, request, pi, allocation, or curatorial order.	1. Improve access to all data associated to a sample, request, or allocation. 2. Allow automatic generation of sample catalogs for the Curation website, reducing the time between updates.
LIVECYCLE ES4 SERVER WITH ADOBE EXPERIENCE MANAGER (AEM)	Document and forms platform used to capture and process information, generate custom communications, manage workflows, manage authoring and publishing of data	1. LiveCycle is a scalable, unified platform that captures and processes information, delivers personalized communications, and secures and tracks sensitive data to reduce paperwork, accelerate decision-making, and ensure regulatory compliance.

Other Initiatives: In addition to the redesign of the Astromaterials Curation databases, we are also engaging in several other informatics initiatives that will help us improve the quality and accessibility of data in our digital repository. We continue to upgrade and host digital compendia that summarize and highlight published findings on the samples (e.g., lunar samples, meteorites from Mars). We host high resolution imagery of samples, including newly scanned images of historical prints from the Apollo missions. Finally we are creating plans to collect and provide new data, including 3D imagery, point cloud data, micro CT data, and external links to other data sets on selected samples.

Together, these individual efforts will provide unprecedented digital access to NASA's Astromaterials, enabling preservation of the samples through more specific and targeted requests, and supporting new planetary science research and collaborations on the samples.

DESIGN AND PROCESSING OF THE LUNAR NORTH POLE MOSAIC. R. V. Wagner, M. S. Robinson, and the LROC Team. School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (rvwagner@asu.edu).

Introduction: The Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) consists of two line-scan cameras aimed side-by-side with a combined 5.7° FOV. The NAC acquired images with a pixel scale of 0.5 m from a 50 km near-circular orbit from 2009 through 2011, and pixel scales ranging from 0.5-2 m from a 30×180 km orbit since December 2011 [1].

In the northern hemisphere, where the orbit is highest, the relatively large size of NAC footprints allows for complete coverage at consistent, moderate incidence angles and high resolution to a startling distance from the pole. We have used this coverage to produce the Lunar North Pole Mosaic (LNPM), a 2 m/px mosaic from 60°N to the pole (Figure 1), currently released on the internet at lroc.sese.asu.edu/gigapan/. The current version contains 681 gigapixels of image data from 10,581 images [2,3]. We are now expanding this mosaic out to 40°N, which will contain just over 2 terapixels of image data.

Processing: The processing method for the LNPM was driven by the format required by Gigapan.com, the site we used to host the current LNPM product. The site requires millions of 256x256 pixel jpeg tiles at all zoom levels. Thus all subdivisions of the mosaic were selected in powers of 2 in image coordinates, rather than using map coordinates. Most of the processing was done using the USGS ISIS software [4].

To minimize file size used by non-image (null) data, individual NAC images, which are usually long strips with a ~10:1 length:width ratio, were map-projected in square segments. To reduce processing time and allow for parellelization, the image segments were mosaicked into 32,768 × 32,768 pixel tiles, rather than attempting to create the entire mosaic in one step (future versions will use 16,384 pixel tiles, to improve speed and memory usage in post-processing). Images included in each tile were selected using a database containing the bounds (in map X/Y space, rather than latitude/longitude) of each NAC segment.

The final processing step used a combination of ISIS and ImageMagick to scale the tiles to all resolutions from full size to a single 256x256 pixel tile containing the full LNPM, add resolution-dependent feature name and lat/lon grid annotations, and split each tile into correctly-named 256x256 pixel subtiles.

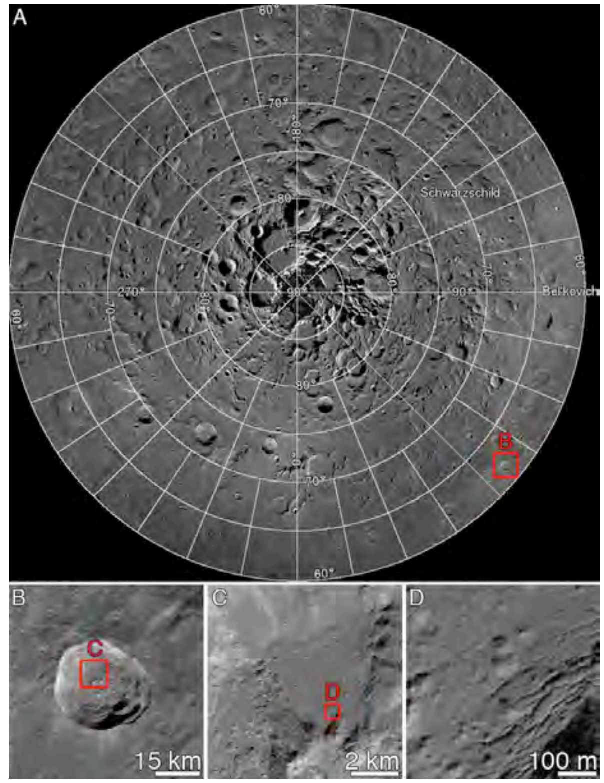

Figure 1: Panel A shows a zoomed-out view of the annotated version of the current Lunar North Pole Mosaic. Panels B-D show increasing zoom levels of a portion of Thales crater. Panel D is a single full-resolution tile from the final product.

Image Selection: Images for the LNPM were selected in three different ways, depending on the latitude range.

Collars (60-82°N): The LNPM is largely made up of "collars" of NAC images: for one-month periods, the NACs would image a specific latitude band on every orbit or every other orbit. Due to the high orbital altitude in the far northern hemisphere, NAC footprints on adjacent orbits overlap, so this imaging sequence produces seamless mosaics with consistent lighting at a given latitude. The released LNPM contains 17 complete and partial collars, and we have since acquired five additional collars to improve lighting uniformity in future updates.

Polar Region (82-90°N): The central section of the LNPM does not consist of collars. Instead, it is an expanded version of the 85.5-90°N north pole NAC mosaic [2,5]. The images are primarily from northern summer, with a sub-solar latitude north of the equator.

Image mosaicking order was based on [6]: first sort the images into 0.5° sub-solar latitude bins, then sort within each bin by the difference between the sub-solar longitude and the longitude of the southern end of the image. Pole-crossing images were trimmed to remove the part of the image on the opposite side of the pole from the sub-solar point. This list was then manually adjusted to clean up areas with inconsistent lighting, using a 100 m/px preview mosaic created using pixel-by-pixel, lowest-incidence-angle ordering (a very slow algorithm, which leaves some edge-of-image artifacts) as a "best possible" reference image.

Southern Expansion (40-60°N): Below 60°N, it is no longer possible to create true collars, as the ground tracks of adjacent orbits are farther apart than a single NAC pair can cover. For the future 40-60°N expansion of the LNPM, we are selecting images from the large existing image data set and targeting new observations to fill gaps in the high-Sun coverage. We are restricting image selection to those with a beta angle (angle between the orbital plane and the Sun-Moon vector) less than 45°, resulting in over 47,000 images in this region. The southern expansion campaign is estimated to finish sometime in 2015.

The ordering criteria have not yet been finalized for this expansion. While a simple "minimum incidence angle" approach may work, it will likely lead to many locations where adjacent images are lit from opposite directions. We are currently looking into algorithms to find clusters of images with similar lighting direction, so that while the mosaic as a whole may not have uniform lighting, there will be near-uniform regional lighting.

A note on sampling scale: This extended mosaic is sufficiently large that distortions from the polar stereographic projection will produce a significant difference in pixel scale between the center and edges of the map. While the scale at the center is 2 m/px, at the edge it is only ~1.6 m/px. Fortunately, the native resolution of NAC images improves as you get further south, and is usually slightly better than 1.6 m/px at 40°N, so even at the edges of the map, the mosaic will not be oversampling the original data. Further expansions will not fare as well, however- following the current mapping scheme images below about 35°N will be oversampled, so any equatorial expansion would require a different map projection. Image selection excludes any image with pixel scales worse than 2 m/px.

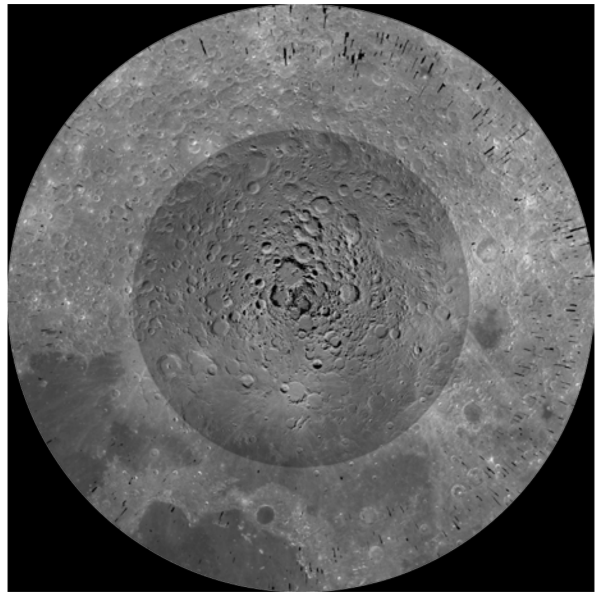

Figure 2: Images available for the expanded LNPM as of March 2015. The dark region in the center is the current LNPM. Close inspection of the upper-right edge shows gores where we do not yet have complete coverage with appropriate lighting.

South Pole: Due to the low orbital altitude near the south pole, a similar product for the southern hemisphere is not possible at this time. Preliminary testing shows that it should be possible to create a mosaic with reasonably consistent lighting out to 80-70°S, and due to the lower orbital altitude, this mosaic would have a higher resolution of 1 m/px. In the future the spacecraft altitude in the southern hemisphere may be raised to allow improved NAC coverage.

References: [1] Robinson et al. (2010) *Space Sci. Rev*. DOI: 10.1007/s11214-010-9634-2. [2] Wagner et al. (2015), LPS XXXXVI, Abstract #1473. [3] http://lroc.sese.asu.edu/posts/738 [4] Anderson et al. (2004), LPS XXXV, Abstract #2039. [5] Henriksen et al. (2013), LPS XXXXIIII, Abstract #1676. [6] Waller et al. (2012), LPS XXXXIII, Abstract #2531.

LANDMARK CLASSIFICATION AND CONTENT-BASED SEARCH FOR MARS ORBITAL IMAGERY.

Kiri L. Wagstaff[1], Gary B. Doran[1], Ravi Kiran[1], Lukas Mandrake[1], Norbert Schorghofer[2], and Alice Stanboli[1]; [1]Jet Propulsion Lab., California Inst. of Tech., 4800 Oak Grove Drive, Pasadena, CA 91109 (kiri.wagstaff@jpl.nasa.gov), [2]Univ. of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822 (norbert@hawaii.edu).

Introduction: Mars orbital mission archives continue to grow. For example, the HiRISE instrument on the Mars Reconnaissance Orbiter has returned >75,000 multi-band images at very high resolution (~0.3 m/pixel). While it is possible to search for images based on image parameters such as target location, season, or illumination angle, there is also a science-driven need to search for images that contain particular features of interest, such as craters or dark slope streaks. Currently this is done by time-consuming manual review of all possible relevant images.

We aim to enable *automated content-based search* through large volumes of orbital image data. Using machine vision and machine learning techniques, we have constructed a system that leverages a small initial investment of time in providing hand-labeled examples of surface features of interest to enable the automated classification of features in new and unseen images. We have integrated these landmarks into the Planetary Data System (PDS) web search interface to allow open access to content-based searching.

Approach: We used a salience-based detector to identify candidate surface features ("landmarks") within Mars orbital images, then manually labeled them by type. We used the labeled data set to train a machine learning classifier that could then predict the type of new landmarks in previously unseen images. We saved the detected and classified landmarks to a database that is now used by the PDS to provide content-based search in HiRISE images.

Landmark detection. The salience-based landmark detector improves on an existing contour-based salience detector [1] in three major ways. First, it uses a genetic algorithm to identify the optimal salience calculation as a combination of Canny edge detector and pixel-based salience. Second, it extracts a bounding box around the area of interest, which allows for the incorporation of nearby context when classifying the landmark. Finally, it employs an expanded list of descriptive attributes for each landmark that includes information about pixel intensities, the distribution of intensities, the dimension of the bounding box, 128 dense SIFT (Scale-Invariant Feature Transform) attributes [2], and 20 context attributes that capture the spatial distribution of bright and dark pixels within the landmark.

Landmark classification. The machine learning classifier is a multi-class Gaussian Naïve Bayes classifier. This model was chosen because it performed best compared to decision tree, random forest, linear SVM, and RBF SVM models. The classifier also provides the posterior probability (confidence) of its predictions. Since the classes of interest that we identified do not encompass all possible landmarks, we allow the classifier to *abstain* from generating a prediction if its confidence does not exceed a specified threshold.

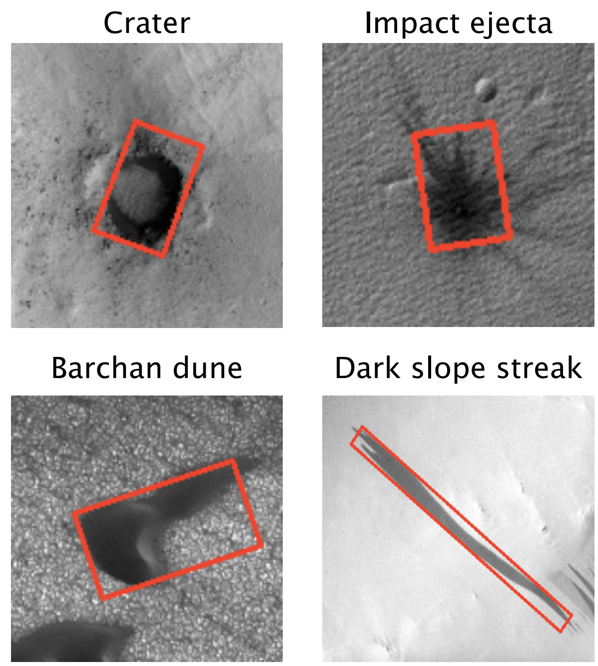

Figure 1. Examples of automatically detected and manually labeled landmarks.

Training Data Set: We assembled a data set containing regions from 65 full-resolution HiRISE images. These regions were chosen to provide good coverage of the landmark classes of interest (craters, impact ejecta, dunes, and dark slope streaks). The landmark detection system identifed 1014 landmarks within the 65 images. We developed a custom graphical user interface (GUI) to facilitate manual labeling of the landmarks. Not all of the detected landmarks qualified as one of the classes of interest. We obtained a total of 126 labeled landmarks (12 craters, 14 ejecta, 43 dunes, and 57 dark slope streaks). Figure 1 shows labeled examples from each class. We augmented this data set with 487 of the unlabeled landmarks (from other classes) assigned to a fifth class we called "None." The total data set contains 613 landmarks.

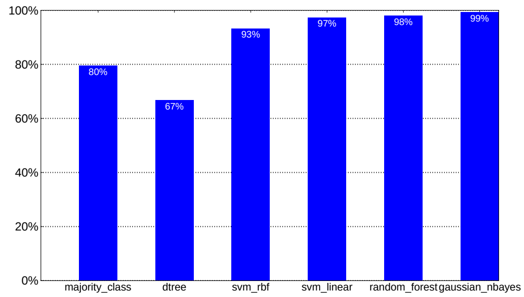

Figure 2. Classifier performance on 613 training examples, using 25% most confident predictions.

We also downloaded browse images for all 38,243 HiRISE images taken with the "RED" channel and applied the trained classifier to identify landmarks in previously unseen images. The results were stored in a PostgreSQL database and used by the PDS to augment the existing web-based Imaging Atlas search interface (more details below).

Results: We evaluated the performance of the landmark classifier using cross-validation on the labeled training examples. We applied a confidence threshold to restrict the classifier's output to the 25% most confident predictions. The Gaussian Naïve Bayes classifier was the best-performing classifier, with 99% accuracy. It also strongly out-performed a simple baseline that classifies any landmark using the majority landmark class observed in the training set (see Figure 2).

This assessment provides the most realistic estimate of how the classifier performs operationally. An abstaining classifier is vital to the full-scale deployment of the system, because within the full set of all HiRISE images, many landmarks are found that fall into none of the currently identified categories.

We applied the trained classifier to the full set of HiRISE browse images, and it identified several new matching landmarks. Figure 3 shows examples of new landmarks found by the classifier for each class. The crater, dune, and dark slope streak landmarks are accurately classified. The impact ejecta example may instead be a polar "spider" feature caused by a gas jet depositing dark material on top of frosted terrain. A closer look at the full image and its imaging conditions would be required to differentiate the two. Nevertheless, the classifier can point searchers to relevant images of interest.

Public Deployment: We stored all HiRISE landmarks detected by the system in a PostgreSQL database. The PDS Planetary Image Atlas[1] added a new search facet (filter) that allows image searches to be

[1] http://pds-imaging.jpl.nasa.gov/search/

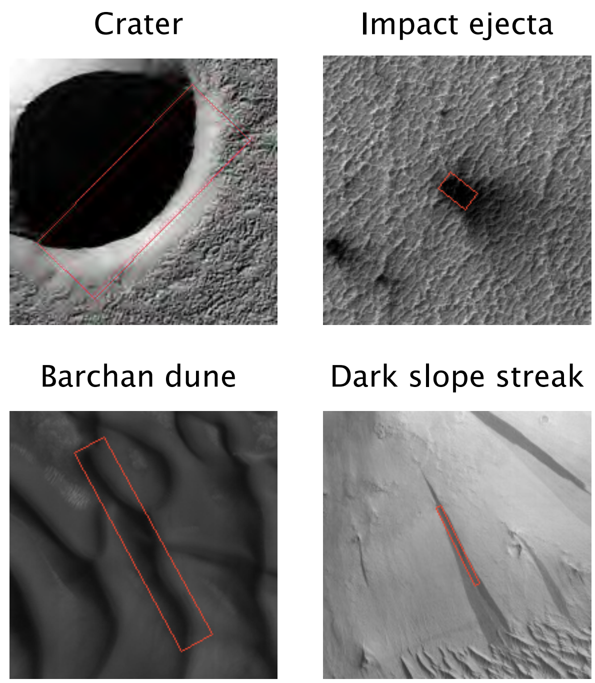

Figure 3. Examples of new landmarks found in HiRISE images by the trained classifier.

restricted to those images containing a particular landmark type at least 90% confidence. Note that the lack of an indicated landmark does not mean that the image cannot contain the landmark, but that it was not detected with sufficiently high confidence. Therefore, positive search results for a given landmark type provide high reliability that the landmark is present, but negative results do not preclude the landmark's presence.

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Webification (W10N) – Data on the Web Platform. Z. Xing[1], E. Sayfi[2], [1]Jet Propulsion Laboratory, California Institute of Technology 4800 Oak Grove Dr, Pasadena CA, 91109, Zhangfan.Xing@jpl.nasa.gov, [2]same, Elias.Sayfi@jpl.nasa.gov.

Introduction: Webification (W10N) is an enabling technology that simplifies the use of data on the web platform. It has been successfully applied to large and complex data sets, such as the ones archived by Planetary Data System (PDS) and Distributed Active Archive Centers (DAAC).

With the proliferation of the web as an application platform, the need for a simple yet robust interface for exposing data to web consumers has become very important. The core idea of Webifcation is to make the inner components of resources directly addressable and accessible via well-defined and meaningful URLs. It abstracts an arbitrary data store as a tree, in which two types of entities exist: nodes and leaves. A node can contain sub-nodes and leaves. A leaf holds data and is terminal. Both nodes and leaves can have attributes.

W10n can be applied to practically any type of file. It can support many different data formats and we're constantly adding new ones: VICAR, PDS, HDF 4/5, NetCDF, GRIB, & FITS, but it's even been applied to powerpoint and excel.

Benefits: These are some of the benefits of exposing data in this way:

- Simplifies client application development
- Semantic URLs, access via HTTP & HTTPS
- Meta info exhange format is JSON by default
- Fully ReSTful style request/response. Read & Write.
- Data format indepence - Standard methods for accessing and using data regardless of storage formats
- Ubiquitous access
- Easy to incorporate new data types
- Enables smart search/query/subsetting of inner components of data
- Promotes reuse
- New applications can be quickly built because the underlying access layer for data and applications is defined

Additional Information: Some more information and some client that were built on top of webification:

- http://scifari.org/taiga/
- http://data.jpl.nasa.gov
- http://rex.jpl.nasa.gov
- http://xglobe.jpl.nasa.gov
- http://webviz.jpl.nasa.gov