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PSUP: A Planetary SUrface Portal

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A B S T R A C T

The large size and complexity of planetary data acquired by spacecraft during the last two decades create a demand within the planetary community for access to the archives of raw and high level data and for the tools necessary to analyze these data. Among the different targets of the Solar System, Mars is unique as the combined datasets from the Viking, Mars Global Surveyor, Mars Odyssey, Mars Express and Mars Reconnaissance Orbiter missions provide a tremendous wealth of information that can be used to study the surface of Mars. The number and the size of the datasets require an information system to process, manage and distribute data. The Observatories of Paris Sud (OSUPS) and Lyon (OSUL) have developed a portal, called PSUP (Planetary SUrface Portal), for providing users with efficient and easy access to data products dedicated to the Martian surface. The objectives of the portal are: 1) to allow processing and downloading of data via a specific application called *MarsSI* (Martian surface data processing Information System); 2) to provide the visualization and merging of high level (image, spectral, and topographic) products and catalogs via a web-based user interface (*MarsVisu*), and 3) to distribute some of these specific high level data with an emphasis on products issued by the science teams of OSUPS and OSUL. As the *MarsSI* service is extensively described in a companion paper (Quantin-Nataf et al., companion paper, submitted to this special issue), the present paper focus on the general architecture and the functionalities of the web-based user interface *MarsVisu.* This service provides access to many data products for Mars: albedo, mineral and thermal inertia global maps from spectrometers; mosaics from imagers; image footprints and rasters from the *MarsSI* tool; high level specific products (defined as catalogs or vectors). *MarsVisu* can be used to quickly assess the visualized processed data and maps as well as identify areas that have not been mapped yet. It also allows overlapping of these data products on a virtual Martian globe, which can be difficult to use collectively. The architecture of PSUP data management layer and visualization is based on SITools2 (Malapert and Marseille, 2012) and MIZAR (Module for Interactive visualiZation from Astronomical Repositories) respectively, two CNES generic tools developed by a joint effort between the French space agency (CNES) and French scientific laboratories. Future developments include the addition of high level products of Mars (regional geological maps, new global compositional maps…) and tools (spectra extraction from hyperspectral cubes). Ultimately, PSUP will be adapted to other planetary surfaces and space missions in which the French research institutes are involved.

1. Introduction

The usual mode of carrying out astronomical research of a planetary solar system body has been based on a single astronomer or a small team of astronomers that performs the analysis of a given dataset. Since the beginning of the 21st century, this approach has however undergone a dramatic and very rapid change due to the advances in the space exploration leading to unprecedented flow of data at various spatial scales and multiple wavelengths. In addition, the existence of new archives, high level products resulting from peer-reviewed studies and specific tools allows meaningful comparisons to be made for scientific, planning and educational purposes.

However, it can be difficult to gather, manage and analyze all these data. Mars is a typical case with a tremendous amount of data from (raw to high level products) coming from various sources and techniques. For instance, global mineralogical and elemental maps of Mars have been produced using a variety of remote sensing techniques including visible/near-infrared (0.3–5.0 μm) imaging spectroscopy (Poulet et al., 2007; Ody et al., 2012, 2013; Carter et al., 2013), thermal (6–50 μm) emission spectroscopy (Bandfield, 2002; Rogers and Christensen, 2007; Koeppen and Hamilton, 2008; Rogers and Hamilton, 2015), gamma ray spectroscopy, and neutron spectroscopy (Boynton et al., 2007; Taylor et al., 2010; Gasnault et al., 2010), with each technique having different sensitivities and limitations. Various image data of the surface are also available including Viking Orbiter (VO) (Carr et al., 1972), the Mars Orbiter Camera (MOC) (Malin et al., 2001) on board Mars Global

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Surveyor (MGS), the THermal EMission Imaging Instrument (THEMIS) (Christensen et al., 2004) on board Mars Odyssey (ODY), the High Resolution Stereo Camera (HRSC) (Jaumann et al., 2007) on board Mars Express (MEx), the High Resolution Imaging Science Instrument (HiRISE) (McEwen et al., 2007) and the Context Camera (CTX) (Malin et al., 2007) on board the Mars Reconnaissance Orbiter (MRO).

To support their data reduction and use them collectively, web-based interfaces and/or specific tools using Geographic Information Systems (GIS) are being implemented (e.g., Christensen et al., 2009; Erkeling et al., 2016; Tirsch et al., 2016; Oosthoek et al., 2014; Marco Figuera et al., submitted). Similarly, we have developed a package of applications, called PSUP (Planetary SUrface Portal), which provides seamless integration of various existing datasets accessible via web-based user interfaces useful for data analysis as well as for targeting and educational objectives. PSUP was built thanks to a joined effort of two French research institutes, namely the Observatoire des Sciences de l'Univers Paris Sud (OSUPS, composed of Institute d'Astrophysique Spatiale and Géosciences Paris Sud) and the Observatoire de Lyon (OSUL).

In this manuscript we present the current status of PSUP. After an overview of major components of PSUP, we present the various datasets that are available through this portal (section 2). As *MarsSi* has also already been presented to the planetary community (Lozac'h et al., 2015) and a companion paper is dedicated to the detailed description of *MarsSI* (Quantin-Nataf et al., submitted to this special issue), we then focus on *MarsVisu*. We present the user interface and give insights into the layout of the database, the integration of datasets, and the software routines of *MarsVisu*. Afterwards, we illustrate the features of *MarsVisu* by showing some examples. Finally, future development are presented.

2. Components of PSUP

2.1. Overview

PSUP is a web-based interface of two software application platforms for working with spatial data (raster, vector) acquired by various space instruments analyzing the surface of Mars from orbit (http://psup.ias.u-psud.fr/). The first platform of PSUP is *MarsSI* (Martian surface data processing Information System that provides data analysis functionalities to select and download ready-to-use products or to process data through specific and validated pipelines. To date, *MarsSI* handles CTX, HiRISE and CRISM (Compact Reconnaissance Imaging Spectrometer of Mars)) data of MRO, HRSC and OMEGA (Observatoire pour la Minéralogie, l'Eau, la Glace et l'Activité) data of MEx mission and THEMIS data of ODY. The second platform is *MarsVisu* that provides visualization tool of many data products for Mars: image footprints and rasters from the *MarsSI* tool; compositional maps from OMEGA and TES; albedo, emissivity and thermal inertia from OMEGA and TES; mosaics from THEMIS, Viking, and CTX; specific level-4 products (defined as catalogs) such as hydrated mineral sites derived from CRISM and OMEGA data analyses, central peaks mineralogy, CO_2 crocus line… A third and last functionality of PSUP is to archive and distribute the OMEGA data cubes corrected of atmospheric and aerosol contributions with state-of-the-art tools.

2.2. Block diagram

The conceptual design of PSUP is based on a system architecture that needs to give efficient access to data and services irrespective of their origin. It can be identified as functional blocks in Fig. 1:

1. data archive (currently of the Martian surface) acquired by numerous remote sensing instruments. They (will) vary considerably in level, implementation and format. Metadata standards are provided a well-defined means to describe archives, data collections as well as services to the user for scientific and educational purposes;

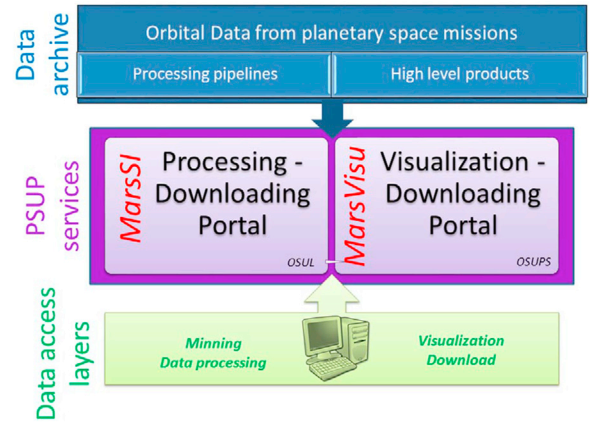

Fig. 1. Block diagram of PSUP including its three major components: data archive, data access layers, and query and compute services.

2. data access layer providing the interfaces to all data and services. It is used both to link the data archives and user queries within the framework of various applications of PSUP;
3. web-based applications *MarsSI* and *MarsVisu* providing the user two interfaces to perform various queries and compute services such as data mining, data processing, visualization and downloading. These services provide the tools for information discovery, small and large scale correlation and analysis of disparate datasets to enable science with PSUP.

2.3. Datasets

The data archive block store datasets (at the moment, catalogs, images, hyperspectral cubes, DTM (Digital Terrain Model) of the Martian surface) organized into logically related data collections, as well as metadata describing the archive and its data holdings. While their management is performed by the application Sitools2 (see section 3), access is provided to the user via a web interface or a specific data mining protocol. The public version of PSUP offers quick access to tens of maps and catalogs as well as thousands of individual and hyperspectral images collected from Martian missions. Table 1 summarizes all the available data through the PSUP portal at the time of the writing of the paper. Commonly-used data products (global mosaics of imagers) are integrated, alleviating concerns about downloading, projecting, and converting data in advance. Compositional maps with a special focus on the OMEGA data set are also included. The data generated by the *MarsSI* application (HiRISE and CTX DTM, CTX and HiRISE images, CRISM cubes) have their footprints and their associated metadata available on *MarsVisu*, enabling data management, data access, data information to the user and in the near-future data interoperability. The catalogs are incorporated into the *MarsVisu* and they can be downloaded as vector layers.

The validation and the quality of all PSUP data products are the results of state-of-the-art data reduction and expertise from various sources including OSUPS and OSUL. The TES-, THEMIS- MOLA (Mars Orbiter Laser Altimeter)- and Viking-based products and the catalogs come from peer-reviewed publications, generally from the PI (Principal Investigators) teams. The other products (*MarSI*-derived, OMEGA-based, catalogs) are validated though pipelines generated by PI teams and/or coming from peer-reviewed works. Fig. 2 illustrates how the level of quality of the PSUP products is derived. For OMEGA and CRISM hyperspectral datasets, this validation step is particularly essential for separating the surface contribution from time-dependent instrumental

Table 1
List of the datasets currently in available on PSUP for processing, visualization and/or downloading. The level definition is shown on Fig. 2.

Dataset	Source	Format	Level	Access
Global mosaics	Viking imager, THEMIS, MOLA, CTX, TES, OMEGA	Raster/Images	L4	*MarsVisu*/Background Layers
Mineral global maps	OMEGA & TES	Raster/Images	L4	*MarsVisu*/Mineral Layers
Images	CTX & HiRISE	Rasters/Images	L3	*MarsVisu* & *MarsSI*
DTM	CTX & HiRISE	Rasters/Images	L4	*MarsSI* & *MarsVisu*
Hyperspectral cubes	OMEGA & CRISM	Rasters/Data cubes	L3	*MarsVisu* & *MarsSI*
Hydrated mineral sites	OMEGA & CRISM	Vectors	L4	*MarsVisu*/Catalogs
Crocus line	OMEGA	Vectors	L4	*MarsVisu*/Catalogs
Regional and global catalogs	Peer-reviewed works based on OMEGA, CRISM, CTX, MOC	Vectors	L4	*MarsVisu*/Catalogs

artifacts as well as icy frost and atmospheric impacts. It is thus important to note here that PSUP benefits the expertise of Institut d'Astrophysique Spatiale (IAS) (one of two members of OSUPS) who is responsible and partner of OMEGA and CRISM teams respectively. A typical example of the complexity to extract homogeneous and coherent information of the Martian surface at a global scale from the OMEGA dataset is described in Audouard et al. (2014a, 2014b). Local expertise at IAS was also mandatory to derive aerosol- and filtered- OMEGA data cubes (Vincendon et al., 2015; Riu et al., 2015), which are a part of the dataset of PSUP through a specific access protocol. Regional and global maps/catalogs derived from peer-reviewed papers delivered with a short explanation and link to the papers are also accessible from the catalog.

2.4. User access

The web-based interface of PSUP is shown on Fig. 3. The user has the choice between three protocols: *MarsSI* (Fig. 3A), *MarsVisu* (Figs 3B and 4) and a protocol allowing the user to specify a query for download directly the catalogs and high level OMEGA products (Fig. 3C).

3. Technical architecture

As illustrated in Fig. 5, the PSUP technical platform is based on a three-tier architecture that separates the user interface (presentation layer), the business rules (application layer) and databases and data storage activities (data layer). Below we describe these three layers.

The data layer is composed of:

- a databases unit containing raster and vector catalogs and their associated metadata,
- a storage unit contains PSUP data and documentation, OMEGA cubes and georeferenced maps for MIZAR plugin (described below).

The content of the data layer is duplicated and saved in a different location to ensure a high level of permanence and accessibility for PSUP. Databases are accessed via JDBC (Java DataBase Connectivity) interface and the stored data by Network File System (NFS) protocol as the communication with the presentation layer (described below) is established with the HTTP (HyperText Transfer Protocol) protocol according to the REST (Representational State Transfer) API (Application Programming Interface) rules. From the user point of view, the datasets and catalogs are accessible through the PSUP portal interface (Fig. 4), but the architecture allows the user to directly reach datasets via webservice request without going through the portal interface.

The application layer is composed of:

- data access components that handle all operations on data provided by the data layer. Two main services are implemented in order to manipulate data and to make the connection between the data layer and the presentation layer: 1) SITools2 (described below) server manages users, security, access, datasets and plugins. 2) MapServer manages spatial data, GeoTIFF images and georeferenced maps intended to be published by an interactive web application (MIZAR in our case);
- WEB services components such as SITools2 REST API allowing the management of different standards and formats like OGC (Open Geospatial Consortium) protocols (WMS: Web Map Service, WFS: Web Feature Service, WCS: Web Coverage Service) and GeoJSON format.

Finally, the only layer visible by the user is the presentation layer that is composed of:

- the end-user PSUP graphic user interface;
- the MIZAR module *MarsVisu* that allows 3D visualization of the Martian georeferenced maps, shapefiles and GeoJSON catalogs. Through this module, we also offer the visualization of the MarsSI footprints and metadata thanks to HTTP web service requests to the WCS server of MarsSI.

It is important to note that the architecture of PSUP data management and visualization is based on two specific tools: SITools2 and MIZAR. These generic tools were developed by CNES in coordination with different French scientific laboratories. More specifically, SITools2 is a secure Client/Server application allowing user and data sources management and access through a Web 2.0 interface. It implements the following functions according to the OAIS[1] (Open Archival Information System) model:

- access including interfaces with the archival storage and data management entities,
- administration including a part of system configuration, active requests functions and customer services.

While SITools2 provides a self-manageable data access layer deployed on the PSUP data, MIZAR is 3D application in a browser for discovering and visualizing geospatial data. This web application is implemented in PSUP as a client of the SITools 2 interface. The choice to use MIZAR was guided by the apparition of the HTML5 and WebGL technologies that make possible 3D visualization in a browser without any plugin. In the same time, massive industrial investments have boosted JavaScript engines performances. In addition, we considered that the “connect anywhere from any support ” through a web application could remain an asset for PSUP data dissemination. As a consequence, all the elements are in place for web applications such as MIZAR to surpass desktop applications for added-value data visualization. More specifically, MIZAR is a

[1] The OAIS (Open Archival Information System) model is an international standard that has been adopted for guiding the long-term preservation of digital data and documents. The OAIS model is an ISO (International Organization for Standardization) standard (ISO 14721:2003): it was developed by the Consultative Committee for Space Data Systems (CCSDS) in 2002, and was adopted as an ISO standard in 2003. The OAIS model is simply a set of standardized guidelines that breaks down an archive into six functional entities to preserve digital data in a long term: Ingest - Archival storage - Data management - Administration - Preservation - Planning - Access.

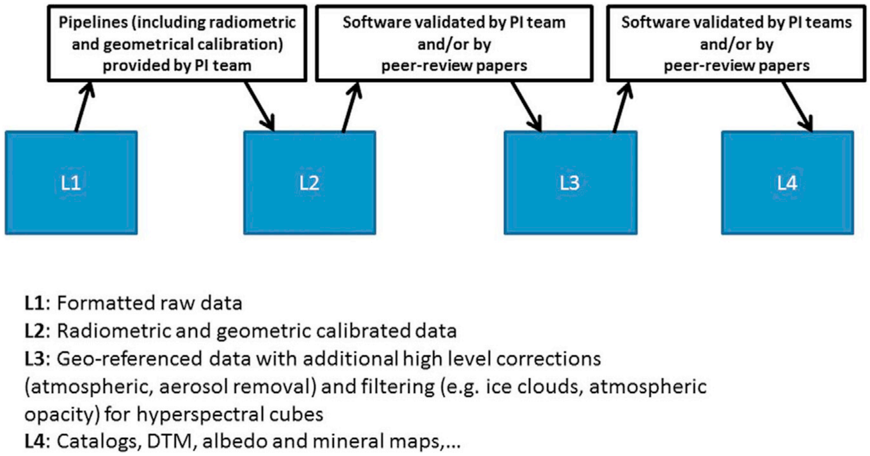

Fig. 2. Data quality pipeline of PSUP products. The definition of each level quality is also indicated.

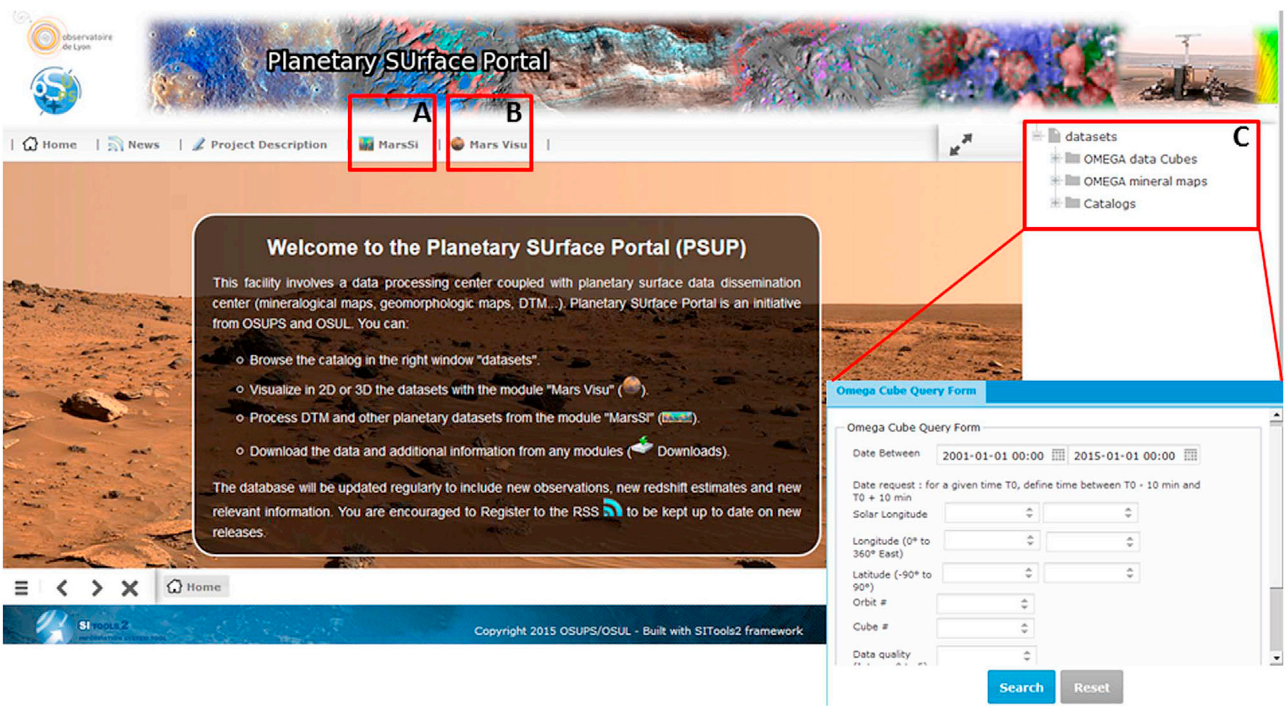

Fig. 3. The access-based user interface of PSUP. (A) User interface of *MarsSI*. The front page of *MarsSI* is presented in detail in Quantin-Nataf et al. (submitted to this special issue). (B) User interface of *MarsVisu*. The display page of *MarsVisu* is shown on Fig. 4. (C) Data mining access for L3+ OMEGA products and catalogs. The user can open a query form to specify various parameters used for the data mining.

CNES web application, developed in collaboration with IAS for the tools requirements and with the support of CDS (Centre de Données astronomiques de Strasbourg) as an astronomical data provider. This web application is modular, based on client-server architecture and it can be used as a library for others web applications. Due to the encapsulation of the webGL technology, the cost of the development is cheaper than a webGL development from scratch. The main asset of MIZAR is to provide a high performance 3D application for discovering and visualizing geospatial data for sky and planets. To adapt to various data catalogs and data providers, a piece of code has been developed implementing both VO and OGC (Open Geospatial Consortium) standards access (e.g. Hare et al., submitted). All these features in a single application make MIZAR an efficient tool for geospatial data representation.

4. Features and scientific examples

The dynamic map webserver *MarsVisu* provides pre-processed level 3 and 4 data (Section 2). The data from different sources can be extracted, scaled, blended, merged, superimposed on one another, and draped over topography for 3-D visualization. A novice user can readily overlay, and blend data from multiple sources. Some basic analysis tools are provided as well, including elevation profiling and distance calculation. Extraction of quantitative values such as albedo, spectral parameter value of selected layers is currently being developed.

The server handles the computational reading and resampling of the various data sets to a common system, then transfers only the relevant, projected portions of each data set to the client application. For instance, HiRISE outlines can be displayed on top of THEMIS thermal infrared mosaic and/or mineral OMEGA map, while extracting a MOLA

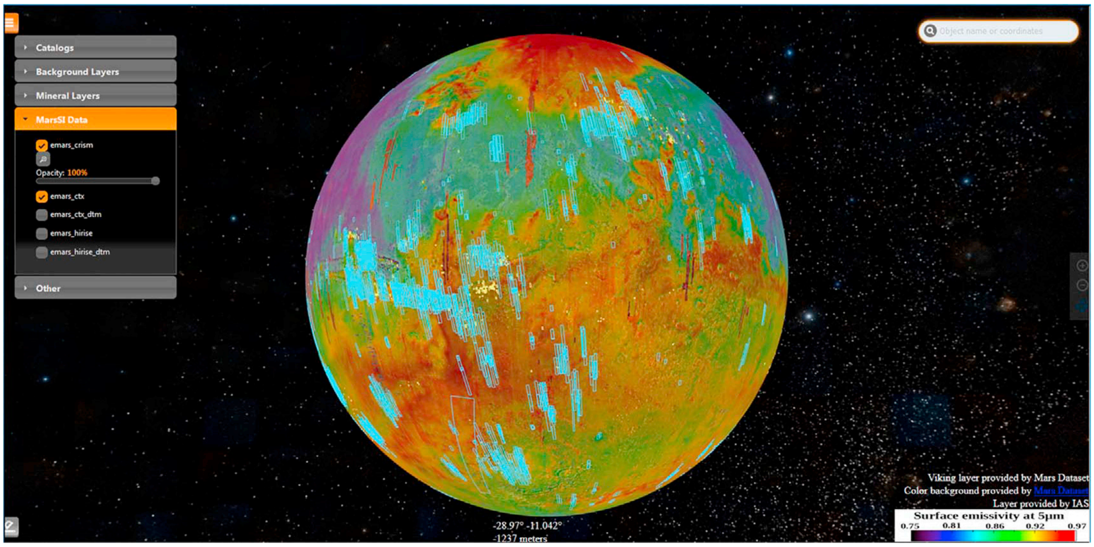

Fig. 4. Example of the *MarsVisu* visualization tool. On the left, the four vertical tabs named "Catalogs", "Background Layers", "Mineral Layers", "MarSI Data" allow the selection of rasters and catalogs listed in Table 1. Another tab called "other" contains possible visualization of coordinates grids and atmosphere. The OMEGA-based surface emissivity map of Mars with outlines of the available *MarsSI* CTX (blue footprints) and CRISM (yellow footprints) data products is here exemplified.

topography profile or superimposing a catalog. Upon clicking on the outlines, an additional window appears giving the metadata such as ID name, source file, geographic information, observational conditions, and hyperlinks allowing the data download. Moreover, a preview vignette of the image will appear in order to give an impression of the data quality and data relevance for the user need. A few examples illustrating the applicability and performances of PSUP are shown on Fig. 6.

Scientists can use PSUP information to quickly identify areas that have not been mapped yet as well as to get an overview of the topics the existing maps focused on. Hence, they are able to quickly discover research areas and fields that still require a detailed and/or subsequent study. Especially for young scientists, it could provide an important point of reference for their studies. Using *MarsVisu* as a teaching resource is also an option as the visualization tool exposes undergraduate students to multiple datasets through an easy-to-use, free platform.

The image footprints can be easily located by geographic area or filtered down based on any number of scientific parameters, then viewed without excessively large downloads or extensive knowledge of planetary data formats.

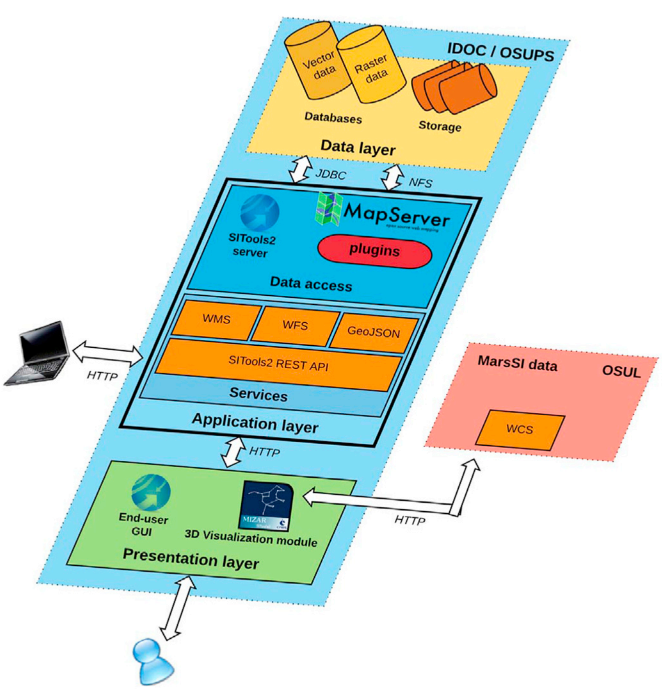

Fig. 5. PSUP platform global architecture based on three major layers (Data, Application and Presentation Layers) described in detail in the text. A specific HTTP web service link to the server of MarsSI has been implemented allowing automatic updating of the MarsSI data products on the visualization MIZAR-based module *MarsVisu*. All acronyms are explained in the text.

5. Conclusion and future plans

PSUP is a useful tool for merging different datasets of the martian surface. It offers a quick access of tens of high level products and thousands of images collected by different space missions as well as hyperspectral OMEGA cubes derived from state-of-art data reduction. It provides a visualization and link of all MarsSI-derived products. These products can be easily located by geographic area or filtered down, then viewed in situ without excessively large downloads or extensive knowledge of planetary data formats. The input datasets on the martian surface will be updated continuously by adding e.g. new regional geological maps and new global compositional maps derived from extensive spectral modeling (Riu et al., 2016).

Numeric data is preserved in PSUP whenever possible. Among the next tools under current development, we foresee to offer the user to quickly extract any information present on the numeric maps (band depth, albedo, spectrum,…). This development requires a release of a new version of MIZAR planned on April 2017. We also aim to develop a generic cube explorer tool in order to explore data and to get a first insight of the data before downloading without any other software installation. Vector data shall be imported or created on the fly, then combined with numeric maps to calculate and report separate values for each shape.

Concerning Virtual Observatory access, Simple Image Access Protocol (SIAP) and Cone Search Protocols (CSP) have already been implemented as a SITools2 plugin and corresponding services have been registered through the VO for cosmology-oriented instances at IDOC. Using the same kind of architecture, the Table Access Protocol web service (more specifically the EPN-TAP Erard et al., 2014) is under development. It is a Java based plugin which used the ADQL (Astronomical Data Query Language) library developed at CDS (http://cdsportal.u-strasbg.fr/

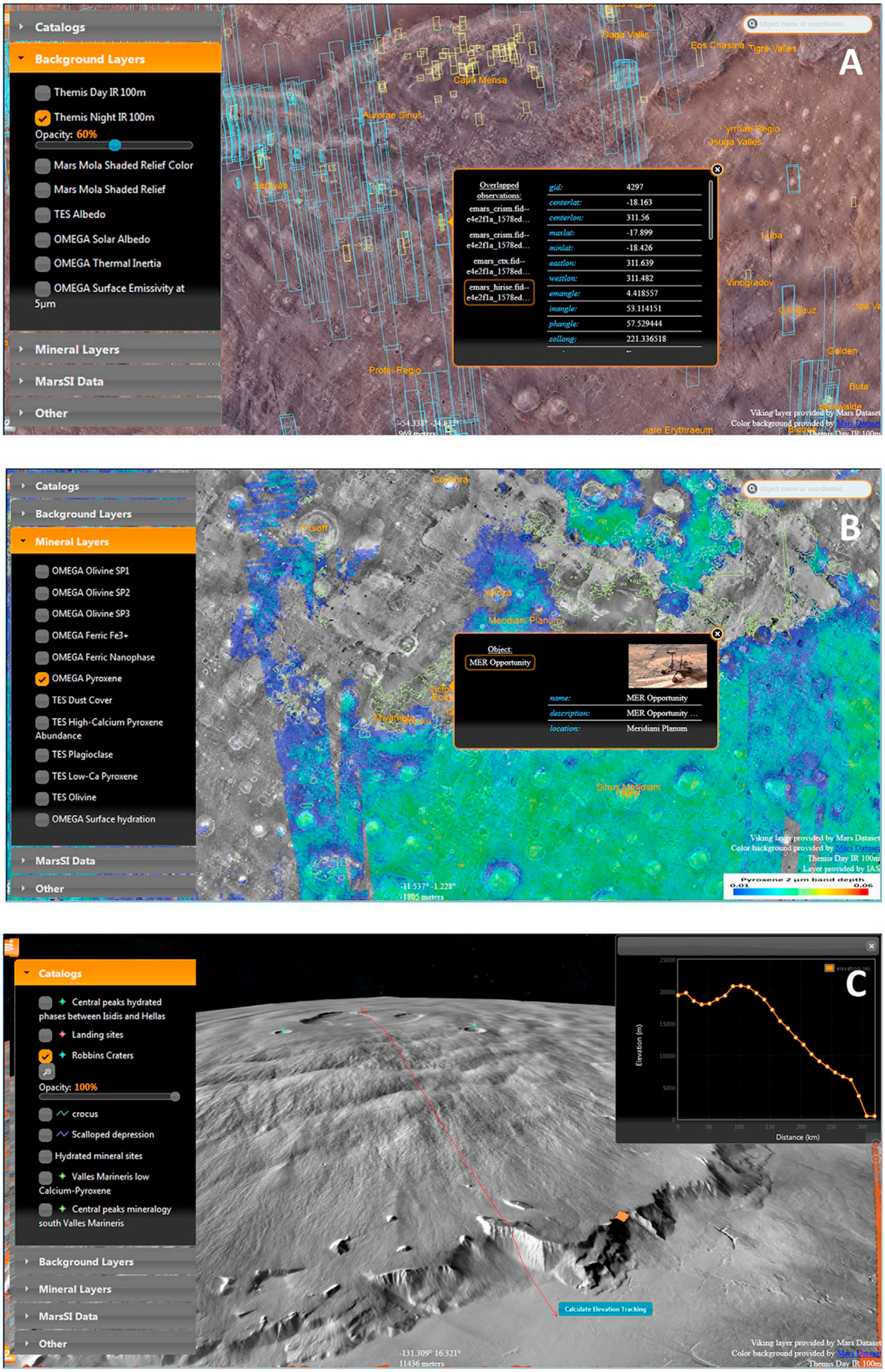

Fig. 6. (A) GIS outlines of the *MarsSI*-derived CRISM, CTX, HiRISE data products over the east part of Valles Marineris. The background image is the merging of the Viking albedo map and the THEMIS nighttime map. A selected region with several overlapped observations (two CRISM data cubes, one HiRISE, one CTX) is pointed out. The metadata of all products can be displayed. Metadata of the HiRISE image is here illustrated in the window. (B) Hydrated mineral outlines over the Terra Meridiani area where one of the two Mars Exploration Rovers landed. The background is a THEMIS nighttime mosaic overlapped by the OMEGA-based pyroxene distribution. The mineral layers window is displayed in the left part. (C) 3D view of Olympus Moons with a topographic profile extracted on the upper right part. The elevation scale is adapted to the size of the zoom. The background image is a THEMIS daytime mosaic. The catalog window is displayed on the left with the selection of the Robbins crater database (Robbins and Hynek, 2012).

adqltuto/). It will be used to deliver PSUP data through the Virtual Observatory.

Finally, the technical architecture of PSUP has been validated and can be adapted to any other planetary surface with the jovian satellites, Mercury and possibly the Moon as the possible next targets for PSUP.

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