**VESPA: ENLARGING THE VIRTUAL OBSERVATORY TO PLANETARY SCIENCE.** S. Erard[1], B. Cecconi[1], P. Le Sidaner[2], A. P. Rossi[3], T. Capria[4], B. Schmitt[5], N. André[6], A. C. Vandaele[7], M. Scherf[8], R. Hueso[9], A. Määttänen[10], B. Carry[11], N. Achilleos[12], C. Marmo[13], O. Santolik[14], K. Benson[12], P. Fernique[15], [1]LESIA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, Univ. Paris Diderot, Sorbonne Paris Cité, Meudon, France, [2]DIO-VO/UMS2201 Observatoire de Paris/CNRS, Fr, [3]Jacobs University, Bremen, Ge [4]INAF/IAPS, Rome, It [5]IPAG UGA/CNRS, Grenoble, Fr [6]IRAP/CNRS, Toulouse, Fr [7]IASB/BIRA, Brussels, Be [8]OeAW, Graz, Aut [9]UPV/EHU, Bilbao, Sp [10]LATMOS/CNRS, Guyancourt, Fr [11]OCA, Nice & IMCCE/Obs. Paris/CNRS, Fr [12]University College London, UK [13]GEOPS/CNRS/U. Paris-Sud, Fr [14]IAP, Prague, Cz R. [15]Observatoire de Strasbourg/UMR 7550, Fr

**Introduction:** Modern space borne instruments produce huge datasets, especially on long-lived missions. This calls for new ways to handle the data, not only to perform mass processing, but also more basically to access them easily and efficiently. Virtual Observatory (VO) techniques developed in Astronomy during the past 15 years can be adapted to address this problem, provided they are enlarged to handle specificities of Solar System studies. The VESPA data access system focuses on applying VO techniques and tools to Planetary Science data, and supports all aspects of Solar System science [1]. VESPA (Virtual European Solar and Planetary Access) is developed in the framework of the EU-funded Europlanet-2020 program started Sept 1st, 2015 for 4 years. The objective of this activity is to facilitate searches in big archives as well as in sparse databases, to provide simple data access and on-line visualization tools, and to allow small data providers to make their data available in an interoperable environment with minimum effort. This system makes intensive use of studies and developments led in Astronomy (International Virtual Observatory Alliance, IVOA [2]), Solar Physics (HELIO), and space archive services (International Planetary Data Alliance, IPDA [3]).

**Data services:** the VESPA architecture [1] is based on a new data access protocol, a specific user interface to query the available services, and intensive usage of tools and standards developed for the Astronomy VO [4]. The Europlanet data access protocol, EPN-TAP, relies on the general TAP (Table Access Protocol) mechanism associated to a set of parameters that describe the contents of a data service [1][5]. These parameters are defined to enable queries on quantities relevant to the scientific user, including observational and instrumental conditions. Data services are required to return answers formatted as VOtables, which are handled by all standard VO tools.

Data services are installed at their respective provider institutes and are declared in the standard IVOA registries, so that they are always visible and reachable from query interfaces. At the time of writting, 37 data services are publicly open, and about 20 more are being finalized (see, e. g., [6]). They encompass a wide scope, including surfaces, atmospheres, magnetospheres and plasmas, small bodies, experimental data such as spectroscopy in solid phase, heliophysics, exoplanets, and selected amateur data services. ESA's Planetary Science Archive (PSA) will get an EPN-TAP interface in 2018, and bridges with PDS4 are being studied.

**Data access:** Although accessible in many ways, EPN-TAP data services are best queried from the optimized VESPA user interface, or portal (Fig. 1)

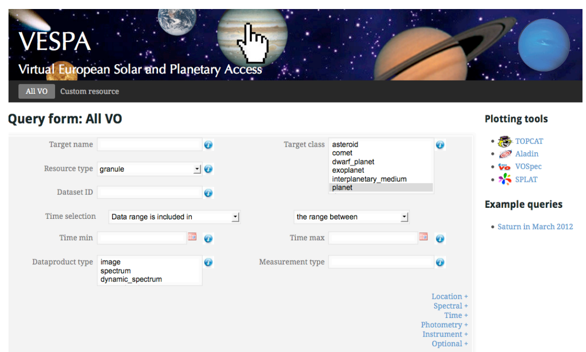


Fig 1: The VESPA search interface: http://vespa.obspm.fr

In the frame of TAP, all data services present a list of granules (usually data files) described by a series of parameters. The Europlanet data access protocol, EPN-TAP, defines a set of mandatory parameters introducing metadata that describe all granules; this is similar to the ObsTAP protocol from IVOA, which describes observational datasets in Astronomy. EPN-TAP metadata introduce both observational and instrumental conditions and are defined to handle the specific diversity and complexity of Planetary Science: ranges on several axes (spatial, temporal, spectral, photometric), measurement type, origin of data, and various references. Location is provided in the most appropriate coordinate system (e.g., sky or planetary coordinates); target-related time (local time and season, through Ls) can be provided when relevant. The VESPA portal uses the mandatory parameters to search for individual granules in all registered data services at once, allowing for discovery of data content unknown to the user. In addition, specific parameters may also be used to describe individual services in more details, and can be used to identify granules more precisely when querying a single service.

All granules provide a link to a data file, or include the data itself in the table when possible (e.g., for scalar quantities). Data description parameters are used to identify adequate VO tools to access, plot and handle the data correctly. They not only provide a description of the file format, but also specify the dimensions, units, and physical quantities, relying on IVOA data models extended for VESPA. For instance, spectra and images are handled in different tools, and spectra measured in radiance or in reflectance are handled differently by the spectral tools.

**Tools:** Metadata are smoothly transferred from the VESPA portal to VO tools according to the IVOA SAMP protocol, with no user intervention. Standard VO tools are connected to the VESPA portal so that they readily display metadata, e. g., spatial footprints are plotted on a 3D sphere in Aladin or Mizar; other metadata such as local time, instrument modes, etc… can be plotted in 2D or 3D with TOPCAT.

The data themselves can be transferred in a similar way for display and standard analyses. Data description is used to select appropriate tools, e.g. TOPCAT will handle all types of tables, Aladin most images and spectral cubes, CASSIS and SPLAT-VO spectra in general (Fig. 2), 3Dview can plot measurements along a spacecraft trajectory, Autoplot is dedicated to extracting data from long time series, etc. Both Aladin and TOPCAT can produce multiresolution maps from large datasets.

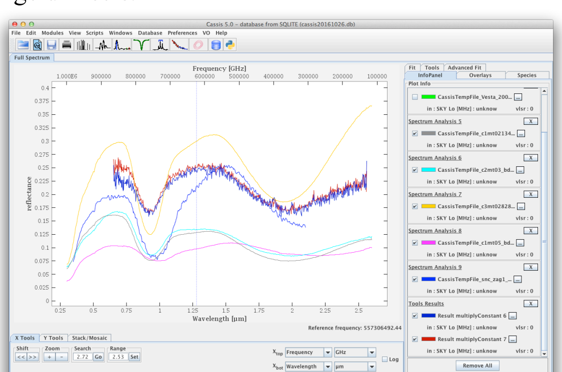

Fig 2: telescopic spectra of Vesta compared to basaltic meteorites from the PDS spectral library in CASSIS.

Most of these tools have been updated to support Planetary Science and to handle specificities of Solar System data, e. g., measurements in reflected light, coordinate systems on surfaces and in magnetospheres, etc. Other, non-VO tools are provided with a SAMP interface so that they can be included in pipe-lines (e. g., ImageJ which now provides conversions and image processing functions to the VO) and in some case new applications have been developed for VESPA (e. g., to handle fits images of planetary surfaces [7], or PDS3 spectral cubes). A significant on-going activity is the development of a connection between the VO world and Geographic Information Systems (GIS), so that EPN-TAP data services can provide links to WMS services which are then handled in QGIS; the intermediate VO layer allows for powerful search functions in the data, and cross-examinations with other datasets.

**Computation services:** another goal is to connect on-line computation services with interfaces similar to the data services, so as to compare observations and simulations more routinely. This activity has obvious applications, e. g., for radiative transfer in planetary atmospheres. A complementary aspect is to provide low level computation functions on-line, e.g., averages, resampling, deconvolution, etc. This is currently supported only to some extent by standard VO tools and ImageJ; in addition, higher level processing such as retrieval of Hapke parameters, multivariate analyses, etc, would also be beneficial and are being studied.

**External contributions:** A procedure has been identified to install data services with little resources, and hands-on sessions are organized twice a year at EGU and EPSC conferences in Europe (see VESPA web site). This is expected to favor the installation of services by individual research teams, e. g. to distribute derived data related to a published study. In complement, regular discussions are held with big data providers, starting with space agencies (IPDA). In parallel, a Solar System Interest Group has just been started in the IVOA, where several VESPA partners contribute; the goal is here to adapt existing astronomy standards to Planetary Science.

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VESPA web site: http://www.europlanet-vespa.eu

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