IDIS Small Bodies and Dust Node: technical innovation and science

M. Giardino[a], V. F. Braga[a,1,*], M. C. De Sanctis[a], L. Giacomini[a], S. Giuppi[a], D. Turrini[a], M. T. Capria[a]

[a]*INAF-IAPS Via del Fosso del Cavaliere 100, 00133 Roma, Italy*

Abstract

It is not trivial, nowadays, to be fully aware of the impressive amount of astrophysical resources that are at hand. Virtual Observatories (VOs) were thus born, in order to provide a simple access to what astronomers look for. In this paper we focus on the original data access services developed specifically for the "Small Bodies and Dust Node" (SBDN), in a VO perspective. We describe the scientific goals along with the innovative technical aspects of the tools, namely the *Comet Emission Lines service*, and the *Cosmic Dust Catalog service*. In the former, an algorithm for the detection of unidentified emission lines has been implemented.

Keywords: comets ; asteroids ; small bodies ; IDIS

1. Introduction

The Integrated and Distributed Information System (IDIS) is supported by the European Commission's Seventh Framework Program, Europlanet Research Infrastructure, as part of the Capacities Specific Programme. It is an

*Corresponding author

Email addresses: `marco.giardino@iaps.inaf.it` (M. Giardino), `vittoriofrancesco.braga@iaps.inaf.it` (V. F. Braga), `mariacristina.desanctis@iaps.inaf.it` (M. C. De Sanctis), `Livia.Giacomini@iaps.inaf.it` (L. Giacomini), `Stefano.Giuppi@iaps.inaf.it` (S. Giuppi), `Diego.Turrini@iaps.inaf.it` (D. Turrini), `mariateresa.capria@iaps.inaf.it` (M. T. Capria)

[1]Present address: Università Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy

Integrated Infrastructure Initiative, ie. a combination of Networking Activities, Transnational Access Activities and Joint Research Activities. The main tasks of IDIS are to provide an easy-to-use web-based platform to give access to available data, to locate teams and laboratories with specific expertise, to exploit synergies between space-based missions and ground-based observatories.A set of tools for describing, accessing and combining information and data from different European and non-European sources are currently under development. Their goal is to offer a Virtual Observatory-like access to a huge amount of planetary science data. IDIS is organized as a network of six web-servers hosted each by a different institute in Europe. In order to deal with the extent of planetary sciences, five different scientific areas (*Interior and surfaces*, *Atmospheres*, *Plasma*, *Planet Dynamics* and *Small Bodies and Dust*) have been pinpointed. Each institute is in charge of a scientific area and their own group of experts supports the activities of the node and the screening of the published node contents.

IDIS differs from similar web based services like ESA PSA and NASA Small Bodies Node and is not intended to replace them but instead to offer an alternative resource. IDIS distinguishes for its distributed nature: each thematic node offers contents and data related to the hosting institute activities. The IDIS SBDN is located at the URL
sbdn.iaps.inaf.it/web/sbdn/home and its personnel is currently member of both the teams of NASA Dawn mission to Vesta and Ceres and of the ESA Rosetta mission to the comet Churyumov-Gerasimenko. Although in prototypal status, node services act as proof of concepts, exhorting users to give their feedbacks : such a contribution is an essential input for the development process and can lead, in the near future, to more mature services, accepted as key functionalities.

2. Content and services

Within the SBDN, resources are grouped in four sections dedicated to specific class of small bodies: Comets, Asteroids, Meteors and Dust. A fifth section is dedicated to general interest resources. The main page also hosts a space dedicated to newsflash on relevant planetary science along with space technology topics.

Internally developed services of the SBDN (which have to be considered its primary resources) are two: the *Comet Emission Lines service* and the *Cosmic Dust Catalog service*. The *Cometary Nucleus Modeling Tool* is an internally developed resource too, albeit no interactive service has been built over it. As we shall illustrate in the next sections, innovative and efficient programming techniques have been applied to obtain these tools.

Emission lines tables have been analyzed and a statistical method to recognize unidentified transition lines across different comets, subsequently implemented in the *Comet Emission Lines service*, has been conceived and applied to the database. Physical and mineralogical parameters of dust grains have been arranged into query parameters, in order to easily filter desired ones on the *Cosmic Dust Catalog service*. The former is the service on which most of the scientific effort has been devolved, together with the *Cometary Nucleus Modeling Tool*, as explained in Sections 2.1 and 2.3.

All the resources, both internal and external, hosted in the SBDN are synchronized with the *Resource List* of the IDIS Technical Node, its purpose being a resource repository for the whole group of IDIS thematic nodes.

2.1. Comet Emission Lines service

Thought to be the spearhead of SBDN (because it was originally built on a single data table published by researchers of our institute) the *Comet Emission Lines service* stores data from four different comet emission lines catalogs and allows to simply operate a query to find the lines of interest. Comets in this catalog are Brorsen-Metcalf (Brown et al., 1996), Swift-Tuttle (Brown et al., 1996), De Vico (Cochran&Cochran, 2002), Ikeya-Zhang (Cremonese et al., 2007) and Hale-Bopp (Zhang et al., 2001) which have been observed with Echelle spectrographs mounted on ground based observatories, with a spectral resolution of 37000 to 60000.

For each line, the peak wavelength (λ_{peak}), species, transition, intensity, equivalent width and distance of observation are provided. Not all of these properties are available for all lines, depending on the original catalog.

λ_{peak} [Å]	Species	Elec. trans.	Vib. trans.	Rot. trans.	Comet	Catalog[1]	Intensity[2]	Eq. width [mÅ]	Dist. [AU]
5586.150	Unid				De Vico	Coc02			0.660
5586.150	Unid				Hal-Bop	ZZH01		17	0.920
5586.160	Unid				Ike-Zha	Cre07	3.347		0.890
5586.180	Unid				Swi-Tut	Bro96	98.000		1.045
5586.220	Unid				Hal-Bop	ZZH01		16	0.918
5586.270	Unid				Hal-Bop	ZZH01		21	0.991
5586.305	Unid				Ike-Zha	Cre07	2.329		0.890
5586.320	Unid				De Vico	Coc02			0.660
5587.520	C2	Swan	0-1	R1(21)	Ike-Zha	Cre07	2.32		0.890
5587.533	C2	Swan	0-1	R1(21)	De Vico	Coc02			0.660
5587.630	C2		(0,1)	R1(21)	Swi-Tut	Bro96	83		1.045
5587.630	C2		(0,1)	R2(20)	Swi-Tut	Bro96	83		1.045

Table 1: A sample of rows of the comet lines tool database

[1] Bro96, Coc02, Cre07 and ZZH01 correspond, respectively, to the references Brown et al. (1996),Cochran&Cochran (2002),Cremonese et al. (2007) and Zhang et al. (2001)

[2] In arbitrary units

The service not only provides a search tool to find the desired lines but also implements a statistical method to spot unidentified lines which could be the mark of the same electronic transition occurring in more than one comet.

The method is based on the difference in λ_{peak} between lines; we call δ this difference. As an example, looking at Table 1, we spot the C2 Swan 0-1 R1(21) transition line in three comets. We define these lines to be a triplet within a $\delta = 0.110$ Å range. Our idea is to measure the δ of all the groups of identified lines (4420 pairs, 1414 triplets, 1097 quadruplets, 350 quintuplets and 239 sextuplets, for a total of 7520 groups and 20654 lines) and obtain a distribution (plotted in Fig. 1) for all $\delta(i)$. $\delta(2)$, $\delta(3)$, $\delta(4)$, $\delta(5)$, and $\delta(6)$ respectively refer to the δ of pairs, triplets, quadruplets, quintuplets and sextuplets.

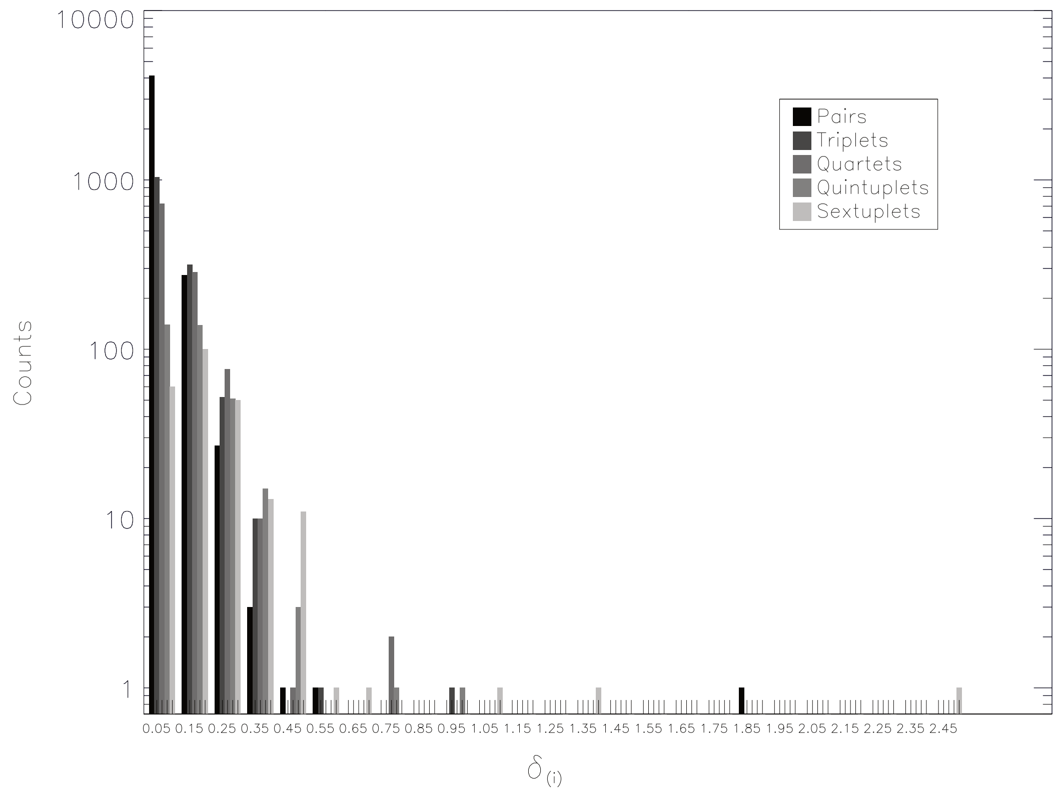

Figure 1: Histograms of the $\delta(i)$ distributions

From the $\delta(i)$ distributions we obtained $\delta_{90\%(i)}$, the values at which the normalized cumulative distributions of $\delta(i)$ reach 0.9.

- $\delta_{90\%(2)} = 0.083$ Å
- $\delta_{90\%(3)} = 0.156$ Å
- $\delta_{90\%(4)} = 0.183$ Å
- $\delta_{90\%(5)} = 0.247$ Å

- $\delta_{90\%(6)} = 0.340$ Å

These $\delta_{90\%(i)}$ are taken as threshold values below which a set of unidentified lines can be considered to be the signature from the same transition observed in different comets. As an example, we can look again to Table 1: the six lines between 5586.150 Å and 5586.270 Å are grouped into a sextuplet of unidentified lines since their δ is lesser than $\delta_{90\%(6)}$.

Although comets in the catalog are only five, sextuplets of lines may appear. This happens because there are three datasets for Hale-Bopp, one for each observation date. Not only the experimental apparatus is different from one observation to the other but the tool is conceived to provide catalogs as they are and not averaged data.

2.2. Cosmic Dust Catalog service

In the last 30 years, NASA's missions have collected various samples of cosmic dust. The acquiring method consists of collector plates mounted on NASA's special aircrafts which flied to the stratosphere at about 20 km of altitude to gather these samples. The NASA Astromaterials Acquisition and Curation Office is involved in the collection and laboratory analysis of dust grains gathered so far into the stratosphere: images and spectra have been obtained with electronic microscopes and energy-dispersed spectrometry. Their properties and spectra have finally been published in a series of catalogs of which volume 15 (Warren et al., 1997) and 18 (Warren et al., 2011), counting 467 and 957 grains respectively, are the only online publicly available ones, at that time. For this reason they also are the only suitable ones to build the database of our service.

The search query is based on the properties of the grains, namely, type, shape, size, luster, transparency and catalog volume.

The property "type" has four possible values: "cosmic", "terrestrial natural contamination", "terrestrial artificial contamination" and "aluminum oxide sphere" and it is the most representative one. This is the key property to distinguish cosmic from non-cosmic dust grains and was assigned to each sample by NASA's Curation Office after analysis of other properties. Luster, transparency and shape are qualitative properties, assigned by visual evaluation; size is a quantitative property assigned by laboratory measurement.

Images of both the grain and its spectrum are opened once a grain is selected using the tool. Unfortunately, spectrum raw data is currently not made available from the original curator of the catalog. This means that it is possible to recognize emission lines of some elements from the spectrum image (some of them are marked with the element's name) but no rigorous analysis can be done.

2.3. Cometary Nucleus Modeling tool

The thermal evolution of comets can be simulated applying the conceptually simple equation of heat to their nucleus

$$\rho c \frac{\partial T}{\partial t} = \nabla[K \cdot \nabla T] + Q_{H_2O} + Q_{CO_2} + Q_{CO} + Q_{tr} \tag{1}$$

where ρ is the mass density, c the specific heat, K the heat diffusion coefficient, Q_{H_2O}, Q_{CO_2} and Q_{CO} are the specific energies inflow/outflow due to the sublimation/condensation of ices of the relative species and Q_{tr} is the energy released during the amorphous to crystalline ice transition (De Sanctis et al., 2005).

Geometry considerations, the starting conditions of the orbit, temperature and composition, affect the calculus in a non trivial way. Thus, a very sophisticated code has been developed during the course of many years to simulate the evolution of a spherical comet (Coradini et al., 1997a,b; De Sanctis et al., 1999; Capria et al., 2000a,b). The temperature at different layers, stratigraphy as well as the gas flux are calculated by the code.

Samples of simulations are exposed in this section of the SBDN, to illustrate the potentiality of this code. External teams which are interested in dedicated modeling of their comets of interest have the possibility to ask for them. ROSETTA team already asked for a theoretical estimation of the surface temperature of comet Churyumov-Gerasimenko, the very target of their mission (Schoenmaekers&Bauske, 2004).

2.4. External resources

Across the web, numerous space science and astronomy sites with facilities' contacts, interactive services, databases and information can be found. These resources are all spread over different sites of different institutes, universities, research groups. Among these, resources on small bodies have been listed and linked. Completeness is far from being achieved but we consider this section of the SBDN to be representative of IDIS goal: an easy access to existing resources. A special mention goes to the Virtual Meteor Observatory (VMO), part of the Europlanet project. VMO is a database of meteor observations, locations, observers and instruments used for observations.

3. Software technology

As platform for the web node, a solid enterprise-level framework has been chosen. The Liferay (Liferay, 2013) Portal platform, developed by Liferay inc.represents both an advanced development infrastructure and a rich content management system. The enterprise edition of this product requires a commercial license, while the community edition, has been released under an open source GNU LGPL (FSF, 2007) license to developers, without advanced features and no customer services: the latter was chosen for the node, offering a cutting-edge inexpensive solution for our purposes. Moreover, Liferay Portal is used by a wide community of users, a crucial resource to be considered during development.

3.1. Content management

For content management, the Liferay structured data model has been used to define the data items required for the node purposes. This data model is based on the model/view pattern (Rumbaugh et al., 1991), exploiting the decoupling between data and its visualization. This is obtained by defining multiple views for a single data model, thus implementing different aspects of the same data. In Liferay terminology, the model is named “structure” and the view is the “template”.

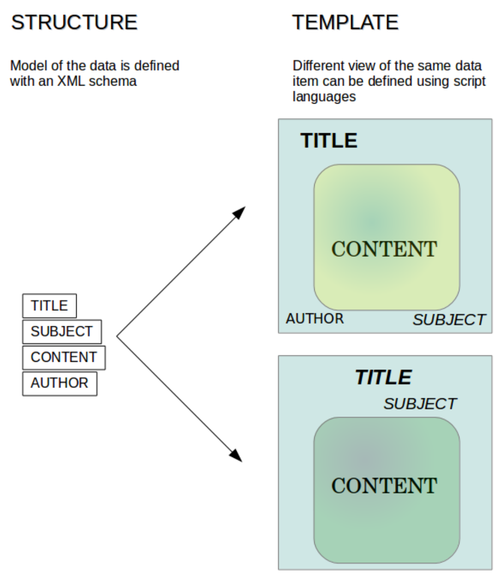

Figure 2: Liferay data model

The node developer defines structures and templates while content contributors use these elements to create and publish node contents. Keeping the roles separated means non-overlapping of responsibilities and an optimized work flow. When defined, a structure leads to a new document type that node users can associate with new content, filling in all required fields in the standard creation form. Therefore content contributors are relieved of any presentation issue.

For our node we defined these three structures:

- Node Resource item: used to represent each single resource (both internal and external) presented in the node
- Node Announcement item: used to publish news about the node activity
- Planetary news item: used to publish general news about planetary science For each of these items, specific visualization templates have been produced to organize a context-dependent presentation. Templates were defined using the Apache Velocity language.

3.2. Service architecture

Services developed under this node are in the category "data access and visualization". The target reference architecture for this class of software products is based on a three-tier concept (Fowler, 2002). Both services follow the same application design: differences between them lie in the data models and in the graphical user interfaces. The persistence tier of the application is based on the MySQL database engine. Specific relational data schemas have been produced to represent the scientific data items and their implicit and explicit relationships among them. The data access tier is wrapped into a set of software methods, written in the Java language, communicating via JDBC with the persistence tier to extract data values. Finally, the presentation tier has been developed using the GWT technology. We decided to take advantage of it by means of the Vaadin library, a software library wrapping the GWT itself and allowing an higher abstraction layer using the Java language plus a widget set.

4. Virtual Observatory features

In the frame of the Europlanet IDIS project, a joint research activity was focused onto the development of suitable data models and techniques related to the "virtual observatory" approach for planetary science. Such effort specifically produced both a data model and an access protocol.

The access protocol, named EPN-TAP (Erard et al., 2014), is based on the IVOA TAP and is a protocol to remotely access data represented in table format. The EPN-TAP extends the IVOA TAP for planetary science, offering a specific tool to realize access services for planetary datasets. Potentially, a data service implemented in the EPN-TAP can be registered into the IVOA registry system and thus made publicly accessible to any IVOA compliant application. One of these applications is TOPCAT (Taylor, 2005) , a portable client tool allowing an easy access and visual interaction with these kind of services. To demonstrate the potentiality of this approach, we created an original EPN-TAP service based on the *Cosmic Dust Catalog service* already described earlier in this article. Starting from the table based model for the cosmic dust particles, we translated it in a TAP compliant structure and then exposed this new structure as a TAP service.

Outcome is that these two dust catalogs can be now easily accessed with

IVOA compliant applications, during normal querying activities, among other worldwide data sources. A detailed explanation of this functionality can be found in the Dust section of the node.

5. Conclusions

By integrating software engineering techniques for web development and science analysis, work effort on SBDN produced an interesting result in the field of web based services offered to planetology science. Services offered, although in prototypal state, represents a basis for the development of additional functionalities in the frame of a virtual observatory for planetology, in accordance with the guidelines defined during the Europlanet-IDIS project.

By accessing the node, the user has both the chance to try some typical feature for a virtual observatory application and to browse an organized resource collection, the contents of which are meant to support the scientific community. The SBDN is, in this sense, a little manifesto of our idea of science usability for the community.

In the near future we plan to promote our node between planetary scientists, as we are willing to receive useful feedback. We also plan to extend services with additional data and to implement new services: we are currently working on a visible and infrared asteroid spectra dataset from Dawn/VIR mission to Vesta and Ceres).

Acknowledgements. A sincere acknowledgement goes to the whole IDIS team in Europe for their collaboration in the IDIS project. IDIS EUROPLANET RI is funded by FP7 grant agreement 228319. We would also like to thank Dr. M. E. Zolensky of the NASA Johnson Space Center for his precious correspondence that helped us with the *Cosmic Dust Catalog service*. We also acknowledge Dr. J. Lasue of Institut de Recherche en Astrophysique et Planetologie for its contribution (Lasue et al., 2010) with extracted spectra data from Volume 15 of the NASA dust catalog.

References

Brown, M.E., Bouchez, A.H., Spinrad, H., Johns-Krull, C.M., A high resolution catalog of cometary emission lines, ApJ, 112, 1197-1202, 1996.

Capria, M.T., Coradini, A., De Sanctis, M.C., Orosei, R. CO emission mechanisms in C/1995 O1 (Hale-Bopp), A&A, 357, 359-366, 2000

Capria, M.T., Coradini, A., De Sanctis, M.C., Orosei, R. Chiron Activity and Thermal Evolution, AJ, 119, 3112-3118, 2000

Cochran, A.L., & Cochran, W.D., A High Spectral Resolution Atlas of Comet 122P/de Vico, Icarus, 157, 297-308, 2002.

Coradini, A., Capaccioni, F., Capria, M.T., De Sanctis, M.C., Espinasse, S., Orosei, R., Salomone, M., Federico, C. Transition Elements between Comets and Asteroids, Icarus, 129, 317-336, 1997

Coradini, A., Capaccioni, F., Capria, M.T., De Sanctis, M.C., Espinasse, S., Orosei, R., Salomone, M., Federico, C. Transition Elements between Comets and Asteroids, Icarus, 129, 337-347, 1997

Cremonese, G., Capria, M.T., De Sanctis, M.C., Catalog of the emission lines in the visible spectrum of comet 153P/Ikeya-Zhang, A&A, 461, 789-792, 2007.

de Sanctis, M.C., Capaccioni, F., Capria, M.T., Coradini, A., Federico, C., Orosei, R., Salomone, M. Models of P/Wirtanen nucleus: active regions versus non-active regions, P&SS, 47, 855-872, 1999.

De Sanctis, M.C., Capria, M.T., Coradini, A., Thermal evolution model of 67P/Churyumov-Gerasimenko, the new Rosetta target, A&A 444, 605-614, 2005.

Erard, S., Cecconi, B., Le Sidaner, P., Berthier, J., Henry, F., Molinaro, M., Giardino, M., Bourrel, N., André, N., Gangloff, M., Jacquey, C., Topf, F., The EPN-TAP protocol for the Planetary Science Virtual Observatory, Submitted to Astronomy & Computing, arXiv:1407.5738, 2014.

Free Software Foundation, Inc., GNU Lesser General Public License, Version 3, 29 June 2007, http://www.gnu.org/licenses/lgpl.html

Fowler, M., Patterns of Enterprise Application Architecture, Addison-Wesley Professional, 2002.

Lasue, J., Stepinski, T., Bell, S.W., Automated classification of interplanetary dust particles: Johnson Space Center Cosmic Dust Catalog Volume 15, Meteoritics & Planetary Science 45, 783-797, 2010 doi: 10.1111/j.1945-5100.2010.01059.x

Liferay inc., Liferay Portal 6.1 Developer's Guide, https://www.liferay.com/it/documentation/liferay-portal/6.1/development

Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F., Lorenson, W., Object-Oriented Modeling and Design. Prentice Hall, Englewood Cliffs, NJ, 1991.

Schoenmaekers, J., Bauske, R. Re-design of the Rosetta mission for launch in 2004, ESASP, 548, 227-232, 2004

Taylor, M.B., TOPCAT & STIL: Starlink Table/VOTable Processing Software, ASPC, 347, 29-33, 2005.

Warren, J.L., Achilles, C.N., Todd, N.S., Bastien, R.K., Zolensky, M.E., Cosmic Dust Catalog Volume 15 Particles from Collectors L2036 and L2021, NASA Johnson Space Center, Houston, TX 77058, 1997. http://curator.jsc.nasa.gov/dust/cdcat15/index.cfm

Warren, J.L., Achilles, C.N., Todd, N.S., Bastien, R.K., Zolensky, M.E., Cosmic Dust Catalog Volume 18 Particles from Collectors L2071, L2076, L2079, L2083, and W7068, NASA Johnson Space Center, Houston, TX 77058, 2011. http://curator.jsc.nasa.gov/dust/cdcat18/index.cfm

Zhang, H.W., Zhao, G., Hu, J.Y., A catalogue of emission lines in spectra of Comet C/1995 O1 (Hale-Bopp), A&A, 367, 1049-1055, 2001.