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Spectral stellar libraries and the Virtual Observatory

E. Solano[1,2*]

[1] *Centro de Astrobiología (INTA-CSIC), Departamento de Astrofísica, P.O. Box 78, 28691 Villanueva de la Cañada, Madrid, Spain*
[2] *Spanish Virtual Observatory*

Abstract. In this presentation I will briefly describe the main characteristics of the Virtual Observatory as a research infrastructure for astronomy, identifying those fields in which VO can be of help for the community of spectral stellar libraries.

Keywords : star: atmospheres; stars: fundamental parameters; technique: spectroscopy; Virtual Observatory

1. Introduction

A typical working scenario in modern astrophysics is that in which astronomers make queries to databases with contents of very different nature (scientific publications, observational data, physical parameters,...), and the result of these queries is downloaded through high-capacity networks for their subsequent analysis with high-performance computers.

This framework, familiar to all of us, is, nevertheless, far from an ideal working scenario as it is affected by a number of issues that limit the efficient exploitation of the contents of astronomical archives and services. The major drawbacks are the following:

- Data discovery: The first problem is associated to the data discovery process, that is, the process of finding where the data I am interested in are. A significant number of spectral stellar libraries are easily accessible at different internet sites or available on the excellent web maintained by D. Montes[1]. Nevertheless,

*email: esm@cab.inta-csic.es
[1] www.ucm.es/info/Astrof/invest/actividad/spectra.html

questions on the completeness of the compilation, the efficient search of the available resources and their operability remain open.

- Data access: The second weak point is related to the heterogeneity in the ways of accessing the astronomical services, mainly due to the lack of a standard access protocol. For instance, there are services which provide stellar spectra through a web page which allows queries by different parameters (e.g. MILES[2]). Other resources provide a web page with a list of links to download the files (e.g. ASTRAL[3]) or just a link from where a compressed tar file can be downloaded (e.g. PHOENIX[4]). In this scenario, if the user has to query a relatively large number of services, the amount of time invested in learning different user interfaces, access and download procedures makes the data access a very inefficient process.
- Data representation: Not only the access to the spectral stellar libraries but also the format of these data collections is heterogeneous. Sometimes, the datasets are delivered in FITS format (e.g. ASTRAL), sometimes as zip files containing datasets in ASCII format with a header (e.g. SpeX[5]) or, like the Kurucz models[6], with a header that is the FORTRAN programme required to read the data.

The conclusion to all this is that, putting together pieces of information coming from different astronomical resources is tedious, inefficient and very time-consuming, and clearly hinders the analysis and exploitation of astronomical data.

2. The Virtual Observatory

Give a solution to the problems described in the previous section is the challenge facing the Virtual Observatory (VO), an international initiative that was born in 2000 with the objective to guarantee an easy and efficient access and analysis of the information hosted in astronomical archives. There are twenty initiatives distributed worldwide and grouped around IVOA[7], the International Virtual Observatory Alliance.

The solution proposed by the VO to solve the data discovery problem was the creation of a registry system. Registries (Benson et al. 2011) are sort of yellow pages, a mechanism with which VO applications can discover and select the resources of interest (spectra, images or catalogues).

[2]http://miles.iac.es
[3]http://casa.colorado.edu/ ayres/ASTRAL/
[4]http://phoenix.astro.physik.uni-goettingen.de/
[5]http://www.BrownDwarfs.org
[6]http://kurucz.harvard.edu/grids.html
[7]http://www.ivoa.net

Regarding the problem of data access, VO proposes a standard protocol to query spectroscopic data: the Simple Spectral Access Protocol or SSAP (Tody et al. 2012). According to it, all VO services providing spectra should be able to understand a query formed by the URL of the service, the central position and the radius of the search cone. Theoretical spectra constitute a particular case as the query by coordinates is meaningless. In this case, the protocol establishes a server-application dialogue to identify the parameters contained in the models and the range of allowed values.

Finally, with respect to the problem of data description, VO proposes a standard data model. Data Models are abstract representations that define a common framework for describing astronomical data. The VO spectrum data model (McDowell et al. 2012) contains all the parameters that are necessary to fully describe spectroscopic data and defines the dependences among them. Fields to include fundamental information to perform a scientific analysis (statistical and systematic errors, data quality, aperture size,..) are contemplated in the data model. Credits are also taken into account. This is an important issue because, if they are not properly handled, this may discourage data providers to expose their contents in the VO. The spectrum data model includes different fields to properly propagate information both on the publisher and the creator. Moreover, tools like VOSA[8] provides by default a BibTeX file acknowledging properly all the resources the researcher has made use of (catalogs, models,...) and that can be appended in a straightforward way in the publication.

The Virtual Observatory is not just standards. Standardization is necessary but it represents only the first layer, the other two being analysis tools and VO science. It is important to stress that the Virtual Observatory is a science-driven initiative whose ultimate goal is, with a few standards and a bunch of tools, to produce lot of VO-science, that is, science that cannot be done (or could be done in a much less efficient way) without the Virtual Observatory.

Fig. 1 illustrates the power of the VO standardization. If we want to build the spectral energy distribution of a given object using a VO tool like, for instance, VOSpec[9], the only thing we need to do is to give the name of the object or its coordinates. The application will query the registry to look for spectroscopic services. With the list of services provided by the registry, VOSpec will make the same standard SSAP query to each of them. The services will return data in the same format and in compliance with the spectrum data model. This will allow VOSpec to make basic operations like unit conversion and show all the spectral pieces in the same scale. All this process is carried out in a transparent way for the user.

[8] http://svo2.cab.inta-csic.es/theory/vosa/index.php

[9] http://www.sciops.esa.int/index.php?project=SAT&page=vospec

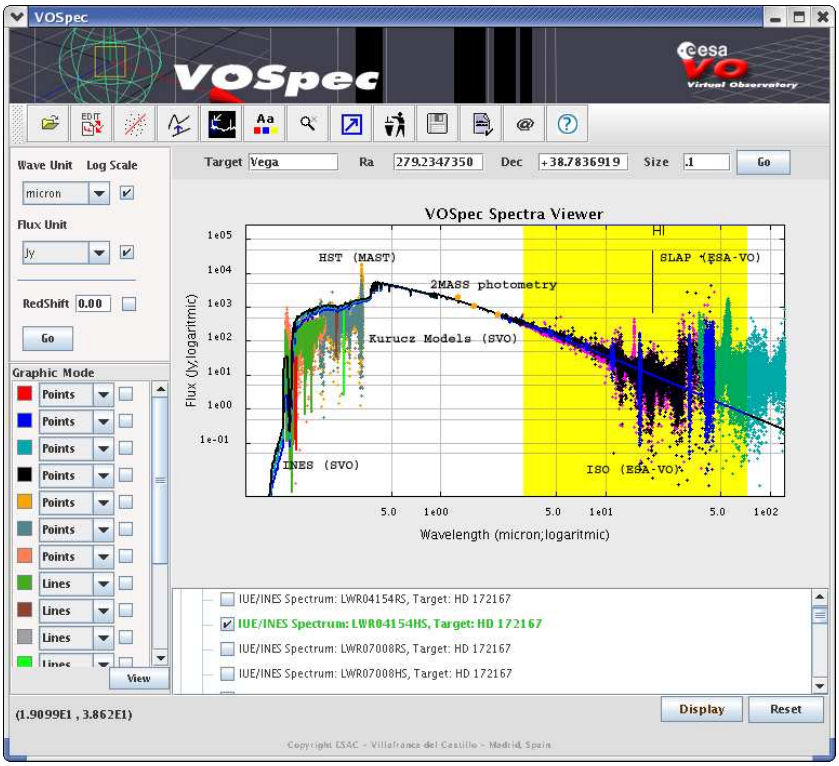

Figure 1. Generation of spectral energy distributions in the Virtual Observatory.

3. Publication of spectral stellar libraries in the VO

There are different reasons why a spectral stellar library provider should publish their collections in the Virtual Observatory. Here I will highlight some of them.

- Importance: The Virtual Observatory represents the framework where to carry out archive-related activities in Astronomy and as such has been recognized by Astronet[10] in Europe and by the Decadal Survey in the US.
- Operational e-infrastructure: The Virtual Observatory is not just a nice idea or a prototype. Its operational phase started some years ago and many data centres (almost a hundred in Europe according to the last census) have already adopted the VO standards.
- Visibility: A good indicator of the success of a project is the amount of people not directly involved in it who have used the data. The Virtual Observatory is

[10] www.astronet-eu.org

an excellent mechanism to enhance the visibility of an archive. Fig. 2 shows the statistics on the SIAP (the protocol to access images in the VO) for the Calar Alto archive. We can see how, in 2012, both the number of queries and the number of retrievals has been larger using SIAP than using the standard web interface.

Spectral stellar libraries published in the VO will be easier accessed by the community which will eventually translate into a higher usage and more citations.

A major limitation in the publication of spectral stellar libraries in the VO is the fact that most of the data providers are small teams, mainly focused on science, and that do not have either the time or the expertise or the willingness to learn how to design, develop, implement and maintain a VO-compliant archive.

To try to alleviate this situation, the Virtual Observatory has carried out a number of initiatives: A guide on how to publish data in the VO is available at the IVOA portal[11] and a number of workshops about this topic were held in the last years. In Europe, the Euro-VO[12] project provides support on how to build a VO-compliant archive to those groups with the know-how necessary to maintain the service. Some national VO initiatives (e.g. SVO[13] or GAVO[14]) also offer to host (with the appropriate credits) the data of those groups interested in having their collections in the VO but that do not want to be responsible of the archive.

4. Usage examples

4.1 Comparison among synthetic collections

We are now in the era of large sky surveys. They are powerful resources for research and discovery because of their data volume, homogeneity and depth. Spectroscopic surveys are, in particular, important because spectra are imprinted with information on the most fundamental stellar parameters.

Large surveys observe many objects of very different nature. The determination of the physical parameters for these objects requires the comparison with theoretical models or observational templates covering different regions of the parameter space. In particular, synthetic libraries have several advantages over observed spectra: they provide absolute fluxes and can be computed for any combination of stellar parameters.

[11] http://wiki.ivoa.net/twiki/bin/view/IVOA/PublishingInTheVONew
[12] http://www.euro-vo.org
[13] http://svo.cab.inta-csic.es
[14] http://www.g-vo.org/

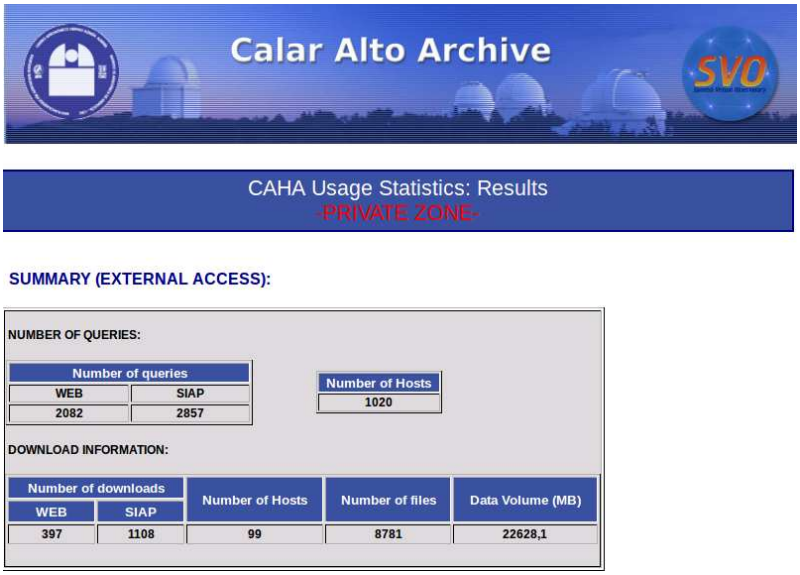

Figure 2. Usage statistics for the Calar Alto archive. We can see how the number of queries and downloaded files is larger using the VO access protocol than the web access.

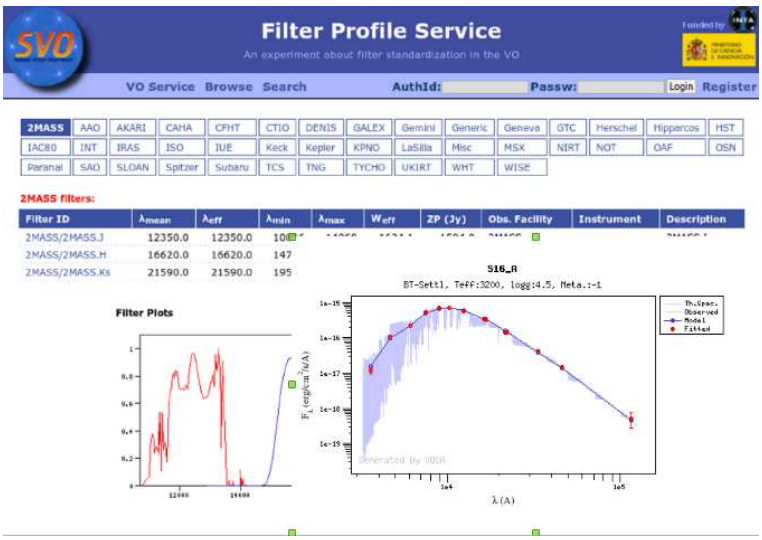

Figure 3. Outputs from the VO SED Analyzer (VOSA) and the Filter Profile Service. Both services have been developed by the Spanish Virtual Observatory.

Typically, large surveys (e.g. Gaia) make use of synthetic libraries that are not disjoint sets but they overlap in different regions of the space of parameters. As the ingredients that form the libraries can be different (different numerical approaches,

different model atmospheres, different atomic and molecular line parameters,...), it is important to perform sanity checks to assess their coherence and identify potential systematic errors before deriving results from observational data. An standardized framework like the Virtual Observatory is the optimum scenario to carry out these sanity checks in an efficient way.

4.2 Enlargement of the covered spectral range

We can also take advantage of the Virtual Observatory to expand the spectral coverage of a given stellar library with spectra available in archives covering other wavelength ranges or to compare with data in the same range for calibration purposes.

Fig. 1 is an excellent example on how efficient the data discovery, access and retrieval is for VO-compliant resources.

4.3 Generation of synthetic photometry

Another typical task is the generation of synthetic photometry to compare with that obtained in large area photometric surveys. VOSA (Bayo et al. 2008) is a VO-tool to gather photometry from different VO services and compare them with the synthetic photometry obtained from different grids of theoretical models and observational libraries convolved with the photometric filters available in the SVO filter profile service[15] to obtain the associated physical parameters (Fig. 3). VOSA is a well-tested, robust tool with more than 200 users analyzing more than 165.000 objects (only in 2012) and around 35 refereed papers making use of VOSA since 2008.

5. Future work

The Virtual Observatory is an evolving infrastructure. Although it is producing science for some years, there are still some lines of work that need to be improved. Among them, I will highlight three types of services:

- Cutouts.

  Asteroseismic studies based on spectroscopic data typically demand the analysis of the variations with time of the line profiles in high resolution spectra. In this case, the download of the whole echelle spectra for the subsequent cutout of the lines of interest is not the best approach. Nevertheless, only very few VO services providing spectra implement this capability.

[15] http://svo2.cab.inta-csic.es/theory/fps/index.php

- Spectral line identification

  Line lists are fundamental components for the computation of synthetic spectra and line identification is a necessary step for all spectroscopic studies. In the Virtual Observatory there exist an access protocol (SLAP, Salgado et al. (2011)) and a data model (Osuna et al. 2011) for spectral lines. Moreover, some tools like VOSpec implement functionalities to access different services (e.g. NIST) and provide information on spectral lines. But the answer from these services includes all the possible transitions in the wavelength range of interest, even though the influence of many of these transitions in the observed spectrum is completely negliglible . What a user would like to have is a service that, taking into account the physical parameters of the objects, (T_{eff}, logg, [M/H]), select only those lines with equivalent widths (and/or central depths) above a given threshold.

  VALD[16] is a service that provides such a functionality but VALD is not VO-compliant. It is now part of another European project called VAMDC[17]. Certainly, some liaison between VO and VAMDC in this field would be very convenient.

- Massive analysis

  The vast amount of data generated by the present and future spectroscopic surveys cannot be analyzed "by hand" but data mining techniques must be used instead. Gaia-ESO, SDSS-SEGUE, RAVE,..., are examples of projects where automated tools for spectra classification and stellar parameters determination will be necessary.

Acknowledgements

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[16] http://www.astro.uu.se/ vald/php/vald.php

[17] http://www.vamdc.eu/

[18] http://svo.cab.inta-csic.es