ABSTRACT

VOSpec is a multi-wavelength spectral analysis tool developed by the ESA Virtual Observatory Team. The tool is able to handle spectra in the VO context as well as providing analysis capabilities and easy integration of spectra coming from different data providers, wavelengths and different metadata. Since its first development from a very simple interface, VOSpec has gone through a series of changes and evolutions converting it into a fully functional Analysis tool for VO data. This paper gives an overview of the VOSpec tool, together with the latest available functionalities.

Key words: VOSpec; Spectroscopy; Virtual Observatory.

1. INTRODUCTION

VOSpec1 is a multi-wavelength spectral analysis tool developed at the European Space Astronomy Centre (ESAC) of ESA by the ESA Virtual Observatory (ESAVO) team. With VOSpec the user can access and visualise spectra from worldwide facilities (e.g. XMM-Newton, HST, ISO, ESO, and others), can overlay and fit to theoretical models and can perform line identification with direct access to atomic and molecular line databases, all registered in the VO. The user can also load their own local data and create spectral energy distributions (SEDs) from both local and VO spectra. VOSpec accesses all spectra in the VO registry that follow the IVOA Simple Spectrum Access Protocol (SSAP; Tody et al., 2008).

In addition to above, VOSpec has a suit of spectral analysis functions which include line and continuum fitting, redshift and reddening correction, spectral arithmetic and convolution between spectra and equivalent width calculations, amongst others. New features include several display modes (tree versus table) and organising functionalities according to the available metadata for each service.

In this paper we describe the main features of VOSpec in section 2 and the analysis functionalities in section 3. Access to theoretical models and spectroscopic lines are discussed in sections 4 and 5 respectively. Finally, in section 6 we describe the new functionalities in the latest release of VOSpec.

2. VOSPEC MAIN FEATURES

The current main features of VOSpec include the following:

- Ability to handle spectra accessible through the IVOA Simple Spectrum Access Protocol (SSAP; Tody et al., 2008).
- Ability to load local spectra (in FITS or VOTable formats).
- Can create an SED with SSAP available and local spectra coming from any region of the wavelength spectrum.
- Can apply an SSAP wrapper onto user’s set of local spectra for immediate availability.
- Common graphic manipulation options are available.
- Easy superimposition of spectra in different units, and unit handling.
- Possibility to save results as Image or VOTable.
- Mathematical functions are available which include line and continuum fitting, spectral arithmetic, equivalent width calculations (see section 3).
- Access to theoretical spectra through the TSAP-like protocol (see section 4).
- Access to Spectral Lines through the IVOA Simple line Access Protocol (Salgado et al., 2009), see section 5.

1http://www.sciops.esa.int/index.php?project=ESAVO&page=vospec
3. SPECTRAL ANALYSIS FUNCTIONALITIES

VOSpec has a suite of spectral analysis tools that have been developed from requirements presented by the scientific community and allow the user to perform basic spectral analysis. These tools include the VOSpec Spectral Calculator, where users can perform arithmetic and convolution operations among spectra and between a spectrum and constant (see figure 1). A number of fitting utilities are available that include continuum fitting to a polynomial or to a black-body continuum spectrum, and line fitting to a Gaussian, Lorentzian or Voigt profile, (the polynomial fitting using a Least Squares fitting method and the others a Levenberg Marquardt Chi-square minimisation algorithm; see figure 2).

Other analysis functionalities include equivalent width, integrated flux and line flux calculations, spectrum filtering, re binning, zero points rejection, spectrum mirroring, redshift correction, wavelength to velocity conversion, spectral line bisector calculation and de-reddening with either the Calzetti law, Cardelli-O'Donnell law or LMC law. For a more detailed description of the spectral analysis tools see Laruelo et al. (2008).

4. ACCESS TO THEORETICAL MODELS (TSAP)

VOSpec accesses Theoretical Spectra through the Theoretical Spectrum Access Protocol (TSAP), see Osuna et al. (2006), which has been integrated as part of the SSAP. The way VOSpec handles theoretical spectra is described in detail in Osuna et al. (2008). For the user, loading theoretical spectra is as simple as accessing and loading SSA spectra. All available theoretical services are listed in the Server selector and the user can select the parameters specific for each theoretical model before sending the query. As is the case with SSA spectra, the theoretical models are sent to the Spectra List in VOSpec and can be displayed with the observational SSA spectra. Current theoretical services available include models of stellar atmospheres, evolutionary synthesis models and models of pre-main sequence stellar discs.

The left of Figure 3 shows an example of the VOSpec tool displaying both a Kurucz model spectrum along with SSA spectra from the Infrared Space Observatory (ISO) service, International Ultraviolet Explorer (IUE) service and the HyperLeda FITS Archive SSA service. As a comparison to the literature, figure 3 also displays the SED of AB Aur from Meeus et al. (2001) which is composed of ISO spectra from the short wave and long wave spectrometers (SWS and LWS; full line in the IR), photometric points from the literature (crosses) and a Kurucz model (full line in the optical).

5. SIMPLE LINE ACCESS

VOSpec is able to access Atomic and Molecular Line transitions through the Simple Line Access Protocol (SLAP) (Salgado et al, 2009) and the Simple Spectral Lines Data Model (Osuna et al., 2009). Figure 4 shows the SLAP Viewer tool of VOSpec, used to access all SLAP services, and the identification of a spectroscopic line using this tool. At the time of writing this paper, the following databases are available in SLAP format and can be accessed through VOSpec. These cover the wavelength spectrum from the x-ray to the millimetre:

- IASD: ISO Astrophysical Spectroscopic Database, the ESA Observational database from the Infrared Space Observatory (ISO). This database covers the infrared spectrum range and has been generated using identified lines from the different ISO observa-
Figure 3. An example of the VOSpec tool displaying observational SSA spectra from ISO, IUE and HyperLeda along with a TSA Kurucz model for the pre-main sequence star AB Aur (left), as compared with Meeus et al. (2001) for the same star, where crosses: observations; full line through the optical data: Kurucz model atmosphere; full line in the IR: ISO-SWS/LWS observations (right).

Figure 4. The SLAP Viewer tool with the main VOSpec window.

- CIELO SLAP: ESA Observational database from the XMM-Newton satellite in the x-ray wavelength range. The SLAP service was created by the ESA-VO team using the DALToolKit utility, a free/public application that can be used by any investigator to publish their own data in SLAP, SSAP and SLAP, depending on the data involved.
- CHIANTI SLAP: An Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas. CHIANTI is a theoretical database and collaborative project involving researchers in the UK, USA and Italy. CHIANTI consists of a critically evaluated set of up-to-date atomic data used to calculate the spectra from astrophysical plasmas. This service covers the wavelength spectrum from the x-ray to millimetre.

6. LATEST FUNCTIONALITIES

The latest version of VOSpec, version 5.0 (the latest version at the time of writing this paper), was released in March 2009. This version includes new features oriented to improve the user experience in the process of retrieving and handling spectra, offering several display modes (tree versus table) and organising functionalities according to the available metadata for each service. These new functionalities are discussed below:

a) Query results displayed as tree or table

Now the user has the option of displaying the spectra list in either tree format (default) or table format. The switch button is available in the tool bar in the main VOSpec window. By selecting the table function, the user can view each SSA service results as a table, with all the...
metadata ordered into columns. The user can also sort the table by dragging columns and order the spectra by clicking on the column headers (e.g. one can order by spectrum format, observation start date, etc). Finally, the table and tree can be undocked and maximised.

b) Server sub-trees rebuilding according to configurable metadata fields

In the tree view option, the user can now build a hierarchical tree for the spectra from each server. By double clicking an SSA service in the Spectra List field a new window appears titled Tree Organizer (see figure 5). The user can then choose the branch ordering according to the available metadata (e.g. by instrument, band, spectrum format etc). This solution gives a lot of flexibility for the user to sort metadata on each server, according to the available metadata, and the scientific goals being pursued.

c) Distance sorting

A new ”Distance” metadata field is now calculated for all SSA servers providing positional RA/DEC metadata parameters. The distance is measured from the target coordinates of the SSA query to the position of each retrieved spectrum. Therefore, as with any other metadata field, users can now sort the spectra according to distance (in both table and tree format).

d) Euro-VO registry

SSA servers are now gathered from the new EURO-VO Full Harvestable VO Resource Registry, compliant with the IVOA Registry Interfaces Specification (Benson et al. (2008)).

e) Query spectral and theoretical servers which are not in the registry

This option allows the user to temporarily add an SSA or TSA server. The feature is titled ’Add SSA/TSA locally’ in the Server Selector window. The user has to provide the endpoint URL, the type of service (SSA/TSA), and a name (see figure 6). The service is added to the normal SSA servers list, and can be used normally during that query. This feature allows the SSA server developer to fully test a server prior to adding it to the registry, as well as allowing users to use SSA resources which have not been registered.

f) New e-support tool

Finally, a new e-support portal is available in which users can submit tickets and receive technical support from the ESA-VO Team. This is accessible through the Help option, Contact ESA-VO Team.

REFERENCES