USING VIRTUAL OBSERVATORY TOOLS FOR SCIENCE

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Abstract. In a dozen years, the astronomical Virtual Observatory has evolved from a prototype to an infrastructure in production, servicing science. Through a few examples, we demonstrate how the VO tools can be used to locate data of interest, manipulate and visualize them.

Keywords: Virtual observatory tools, data discovery, data access

1   Introduction

The idea of the Virtual Observatory (VO) project began around the years 2000, when a data avalanche in astronomy was already forecasted and it became clear that tools to deal with it were needed. The idea was to have all the data existing anywhere in the world be accessible to all and be able to analyze large data quantities outside the researcher's computer.

While we often mention the Virtual Obervatory, one could talk about Virtual Observatories since many independent projects exist around the world. For France, one can mention the VO-France project as well as the EuroVO project for Europe. All VO projects belong to the IVOA (International Virtual Observatory Alliance) to enable coordination among them.

Since the beginning of the VO, an enormous effort of standardization has been achieved. Standards on protocols, data models, meta-data and more have emerged. The VO gives access to a number of databases that are compatible with these standards, as well as tools that were developed in this context.

While all dream-ideas of the beginning of the VO have not been achieved, many things can be done with the Virtual Observatory tools/data. We feel that there is an under-usage of the VO tools due to a lack of knowledge of them in the scientific community. This talk/paper aims at spreading the word of what exists in term of very generic tools/functionalities for scientists.

In the following, we will present excerpts of science cases to show what can be done with a few key tools: `Aladin` (for images), `TOPCAT` (for tables), and `VOSpec` (for spectra). The full tutorials as well as the list of all VO tools are available on the EuroVO webpage (`http://www.euro-vo.org/`). The examples were chosen to answer the following question:

1. How do I deal with large catalogs?

2. How do I find all the available data for one object?

3. How to explore the sky at different wavelengths?

4. How do I visualize spectra?

We will then demonstrate how these tools are able to interact with each other, which is at the core of the VO idea.

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2 How to deal with large catalogs?

TOPCAT is a great tool to deal with numerical tables and catalogues in general. It can be downloaded from the website `http://www.star.bris.ac.uk/~mbt/topcat/` and installed easily. We presented a mini-demonstration of its usage by showing step by step part of the "*Discovery of Brown Dwarfs mining the 2MASS and SDSS databases*" science case (this science case is available entirely at `http://www.euro-vo.org/pub/fc/workflows/BDs.html`). The idea is to search for brown dwarf candidates using color and magnitude criteria. To do so, the 2MASS and SDSS catalogs around the position $08^h30^m +01°30'$ were loaded in TOPCAT and cross-matched together with a $4''$ error, keeping only the best matches. A selection on the cross-matched sources was done using criteria based on color and magnitude (i.e. $u>22.0$ and $g>22.2$, $(J-H)<0.3$ and $(H-K)<0.3$). The full catalogs and the subset can be easily visualized in TOPCAT and this was shown by plotting both on a color-color plot. A single brown-dwarf candidate was found at the end of the process.
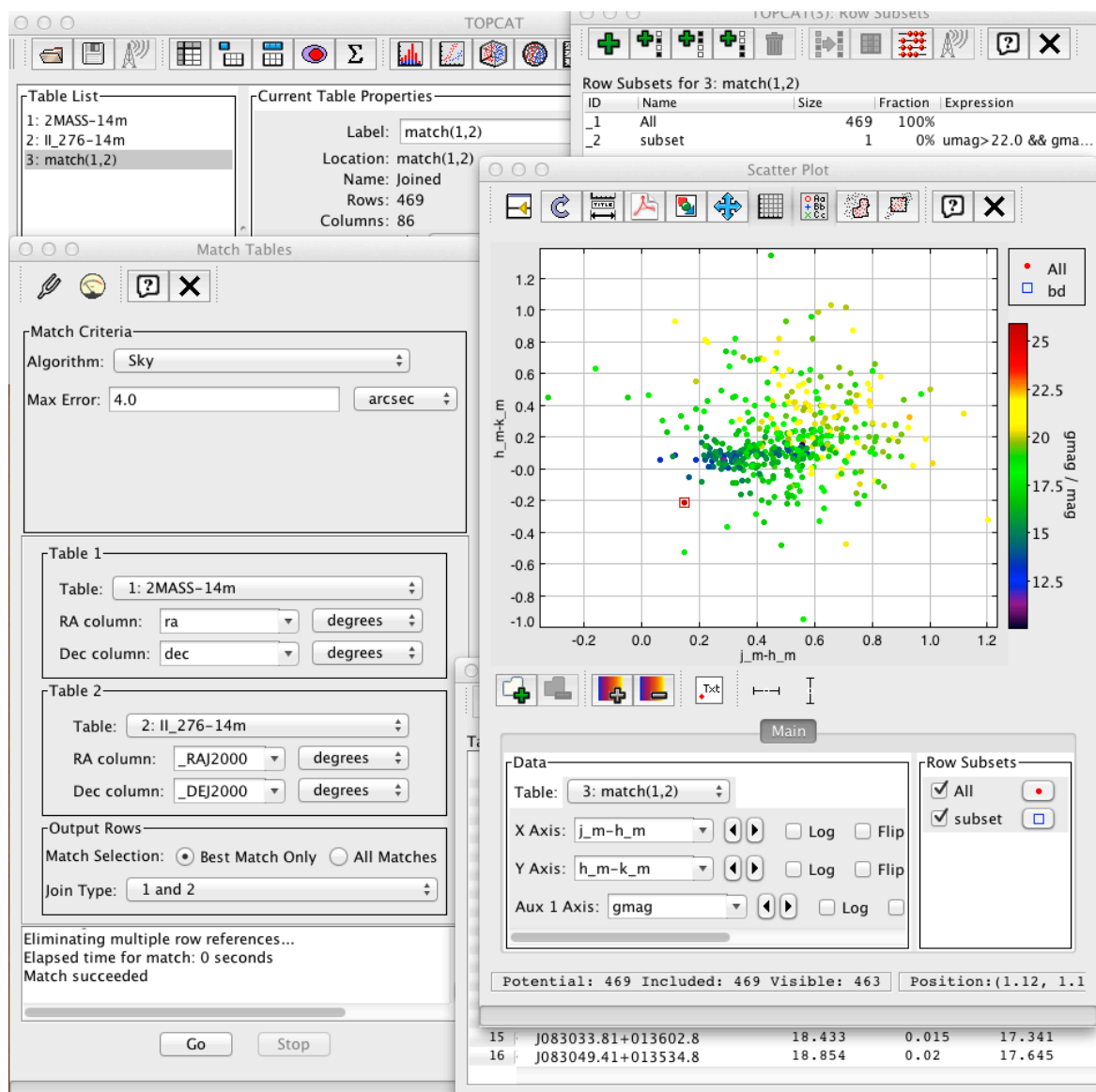

Fig. 1. Using TOPCAT to cross-match, visualize, and do selection of tabular data

3   How to find all the available data for one object?

Aladin is great tool to deal with images, but it is also a portal to the Virtual Observatory in general, which means that one can know about existing data for a region of the sky with `Aladin`, whether this data is a spectrum, a table or an image. We demonstrated how to query all available data for the region of the sky around M51 and how to explore the sky at different wavelengths by loading data from the X-ray (XMM), UV (GALEX), optical (Sloan Digital Sky Survey), infrared (IRAS), radio (NVSS, HI and CO data). We made heavy use of the all sky capabilities of `Aladin` and of the all sky surveys at different wavelengths available through `Aladin` itself. We also loaded catalogues and images specific to the region of M51, made a three color image to visualize the multi-wavelength information, showed the multi-view options and made use of the transparency between the different layers (images, catalogs). This demonstration was based on the Euro-VO science case "*Searching for Data available for the bright galaxy M51*" which is available on the website `http://www.euro-vo.org/pub/fc/workflows/M51.html`.
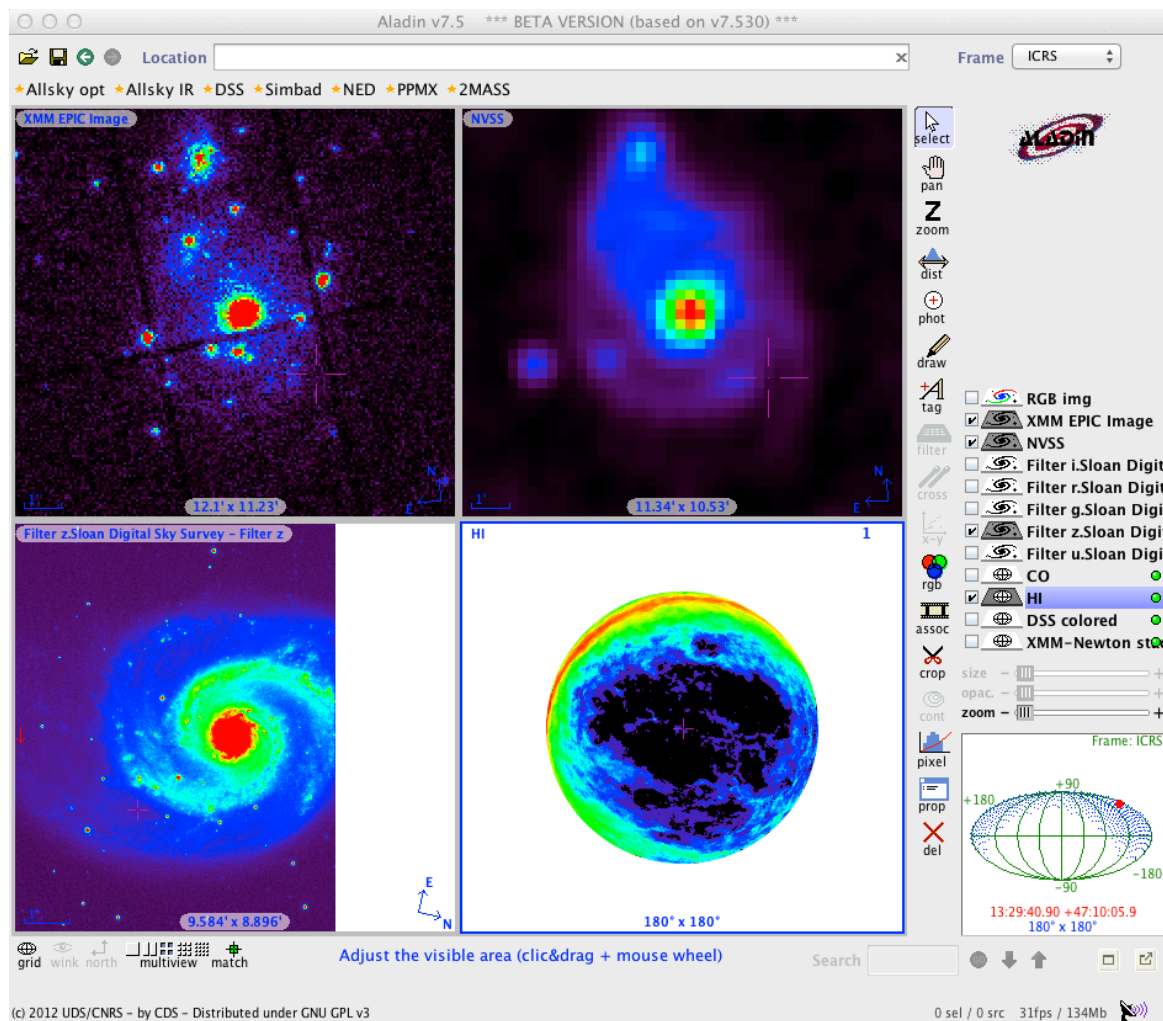

Fig. 2. Using `Aladin` to explore data at different wavelengths in the region of M51

4   Dealing with spectral data with VOSpec

`VOSpec` was chosen as the tool to display spectra. We searched for available spectral data for the star HD 141569. Different spectra from the ISO, IUE, INES, ESO and FUSE data bases were loaded and displayed. Capabilities to zoom in and out, and select a region where shown, as well as the link with theoretical data bases. Indeed, we accessed the NIST atomic spectra database and searched for the line data available for a

wavelength subset of one spectrum where a line was visible. The different possible lines corresponding to it appeared overlaid on the spectrum when browsing over it with the mouse. This mini-demo was extracted from the tutorial "*Classifying the SEDs of Herbig Ae/Be stars*" available on the website `http://www.euro-vo.org/pub/fc/workflows/Herbig.html`.
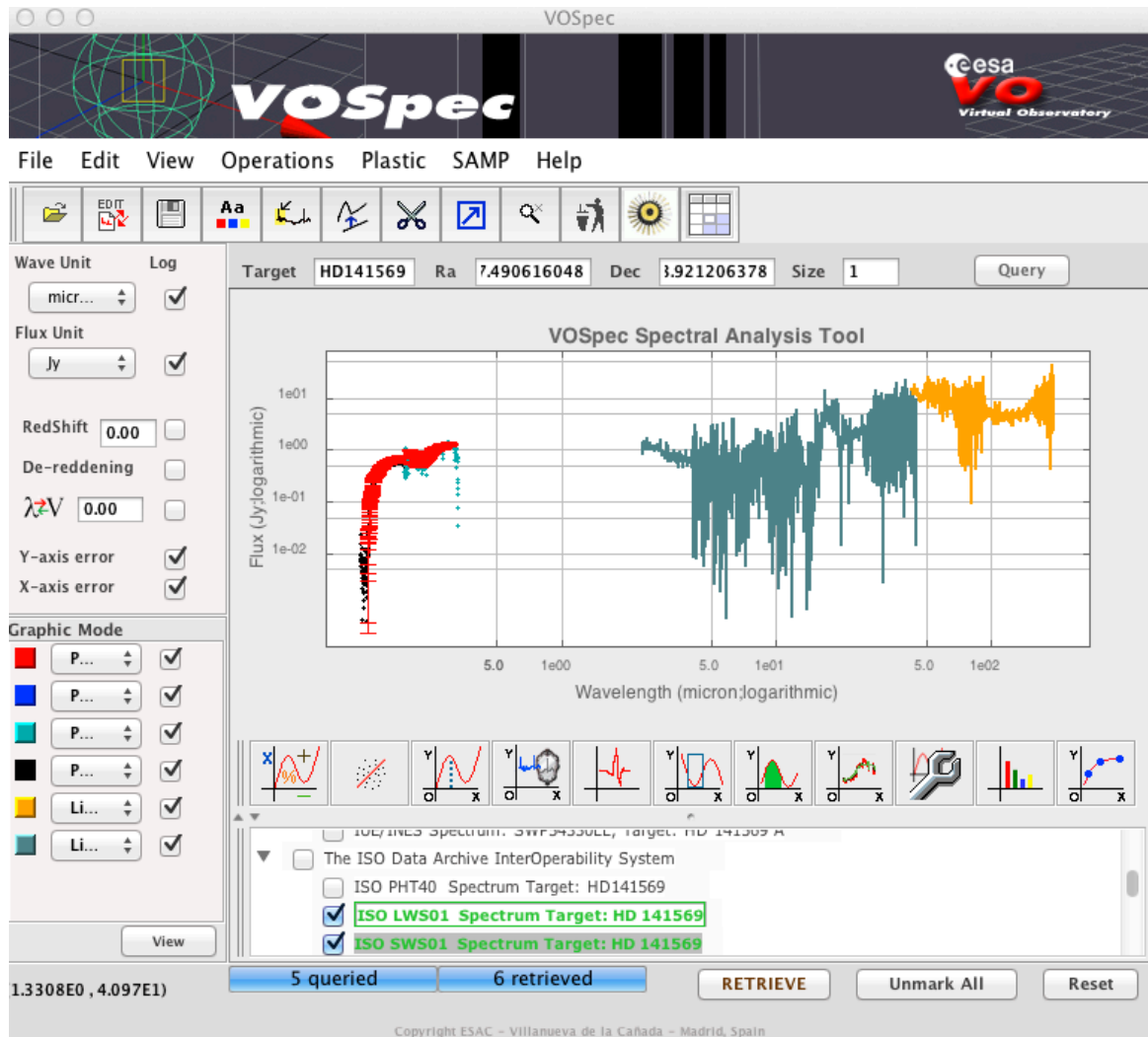

Fig. 3. A typical `VOSpec` session with multi-wavelength, multi-origins spectra loaded for the target HD 141569

5   Conclusion: Interoperability of the tools

After showing independently the `TOPCAT` tool for catalogs, the `Aladin` tool for images and the `VOSpec` tool for spectra, we showed what makes the core interest of the Virtual Observatory project and is based on all the standards developed in this context: all VO tools can interact with each other and function as a single one. We demonstrated this capability by taking the brown dwarf candidate found in the `TOPCAT` mini-demo and sending it to the `Aladin` tool to visualize its location on top of an all sky view. We also showed that selections done in `TOPCAT` can be viewed simultaneously in `Aladin`. We then searched for the star HD 141569 in `Aladin` and looked for available spectra thanks to the `allvo` tab, select some spectral data and load it from `Aladin` to `VOSpec`.

6   Perspectives

Following the recommendations of the Science Commitee, standardization work in on-going at the IVOA level. Current high-priority topics include SEDs (Spectral Energy Distribution) building, cross-match, and complex queries to tabular data.

In order to stay tuned about latest development of VO tools and services, you might consult the IVOA newsletter available at `http://www.ivoa.net/newsletter` . It provides, twice a year, with highlights about new features in VO tools, as well as a summary of VO enabled science papers.