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VOSA: A VO SED Analyzer

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Abstract

VOSA (VO Sed Analyzer)[a] is a public web-tool developed by the Spanish Virtual Observatory[b] and designed to help users to (1) build Spectral Energy Distributions (SEDs) combining private photometric measurements with data available in VO services, (2) obtain relevant properties of these objects (distance, extinction, etc) from VO catalogs, (3) analyze them comparing observed photometry with synthetic photometry from different collections of theoretical models or observational templates, using different techniques (chi-square minimization, Bayesian analysis) to estimate physical parameters of the observed objects (teff, logg, metallicity, stellar radius/distance ratio, infrared excess, etc), and use these results to (4) estimate masses and ages via interpolation of collections of isochrones and evolutionary tracks from the VO. In particular, VOSA offers the advantage of deriving physical parameters using all the available photometric information instead of a restricted subset of colors. The results can be downloaded in different formats or sent to other VO tools using SAMP. We have upgraded VOSA to provide access to Gaia photometry and give a homogeneous estimation of the physical parameters of thousands of objects at a time. This upgrade has required the implementation of a new computation paradigm, including a distributed environment, the capability of submitting and processing jobs in an asynchronous way, the use of parallelized computing to speed up processes ($\sim$ ten times faster) and a new design of the web interface.

[a]`http://svo2.cab.inta-csic.es/theory/vosa`
[b]`http://svo.cab.inta-csic.es`

1 Introduction

Although detailed studies on individual objects are, and will be, obviously necessary, the amount of public archival data available and multi-wavelength catalogs from all-sky survey missions (GAIA, GALEX, SDSS, 2MASS, UKIDSS, AKARI, WISE, VISTA...) are making it mandatory to develop new tools and methodologies that facilitate the analysis of large amounts of multi-wavelength data in homogeneous and efficient ways. In this context, the Virtual Observatory (VO),[1] as a common frame to exchange not only observational data but also theoretical models, plays a very important role.

VOSA is in operation since 2008 [2], with more than 1000 active users (∼10.000 files uploaded by users and ∼1.300.000 objects analyzed), and referenced in ∼ 95 papers published making use of this tool, applying it to different astronomical problems, including asteroseismology [11], OB Stars [10], brown dwarfs ([8],[9],[1]), trasition disks ([5]) or peculiar high proper motion sources in the field ([6],[7]).

In the next sections we will describe a typical workflow in VOSA and give some details about the new architecture. A more detailed description of the functionalities and capabilities of the tool can be found in the on line documentation.[2]

2 SED building

The first step in the VOSA workflow is uploading a user file with a list of objects to be studied. This can be done using the ad-hoc VOSA format or using VOSA's converter to reformat a coma separated value (csv) or VOtable file. This file can contain different levels of information, from just object names to, optionally, photometry (either magnitudes or density fluxes), distances, extinction properties, flags about the detection or upper-limit nature of the values provided, etc. Files with up to 10.000 objects are accepted. Bigger files are automatically split, for performance reasons, into files with up to 10.000 objects.

All this information can be complemented searching in VO services able to provide name resolution, distance information and extinction properties. Gaia TGAS catalogue is already included, providing much more accurate values for distances that allow for a better estimation of other stellar parameters later, in the analysis phase.

Apart from the photometry included by the user in the input file, VOSA also allows to search in more than 30 VO photometry catalogs, including Gaia DR1, so that the user provided SED is complemented by the found data, keeping track of the temporal and quality flags provided by the VO-services.

All the observed (user and VO) photometry must be matched to some filter in the SVO Filter Profile Service[3] to obtain the relevant information needed to properly understand the observed data and convert catalogue magnitudes into fluxes (zero point, effective wavelength, etc) and also to be able to compare observed data with the adequate synthetic photometry for each theoretical model, calculated using the corresponding filter transmission curve.

Once the SED is built, VOSA detects the infrared excess using an algorithm, based on our iterative modification (with outlier rejection approach) of the Lada 2006 parametrization ([4]). Photometric points flagged as "excess" will not be taken into account in the fitting

[1] `http://www.ivoa.net`

[2] `http://svo2.cab.inta-csic.es/theory/vosa/help/`

[3] `http://svo2.cab.inta-csic.es/fps/`

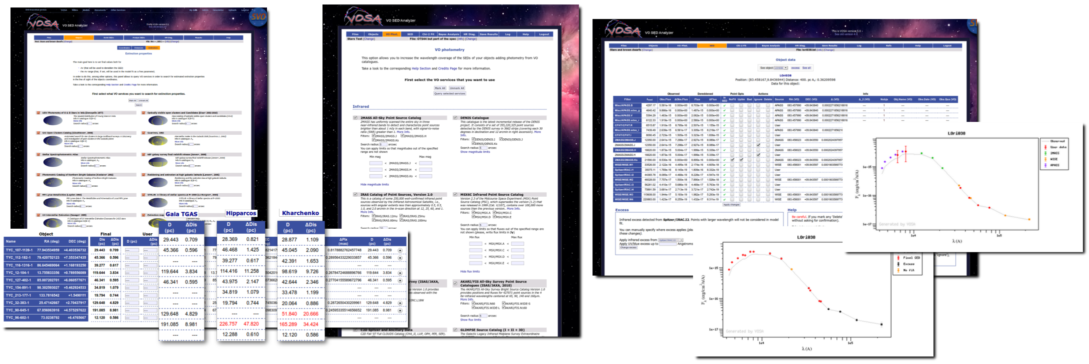

Figure 1: SED building and editing in VOSA.

process if the models chosen are purely photospheric (after the model that best fits is found, a post-refinement of the infrared detection can be made by comparison of the observed SED and the model photometry).

Then the user has the possibility of visualizing the final SED and fine-tuning each SED manually: changing the automatic infrared detection diagnostic, excluding SED points due to blue/UV excess, deleting points, flagging data-points to be treated as upper-limits, etc. Some of these options can be applied together at once to all the objects in the file if desired. Objects flagged as upperlimit are adequately taken into account in the model analysis later unless the user requires not to use them.

3 SED analysis

VOSA offers several options to analyze the Spectral Energy Distributions and estimate physical properties for the studied objects.

First, observed photometry is compared to synthetic photometry for different collections of theoretical models in two different ways: brute-force chi-square grid fitting and Bayesian analysis.

Chi-square fit provides the best fit model and thus an estimation of the stellar parameters (temperature, gravity, metallicity, ...). It also estimates a bolometric luminosity using the distance to the object and the best fit model and making the necessary corrections to take into account the amount of overlapping among the wavelength range covered by different observations. Using the obtained values of these parameters, it also provides an estimation of the stellar radius and mass assuming that the objects is in its main sequence phase. Optionally, a Monte Carlo approach can be selected to estimate parameter uncertainties. In this case, the observed SED is perturbed assuming gaussian noise and a full statistical analysis is done on the obtained values for the fit parameters, including a normality test to check for the presence of an underlying gaussian distribution of the values.

On the other hand, the Bayesian analysis provides the projected probability distribution

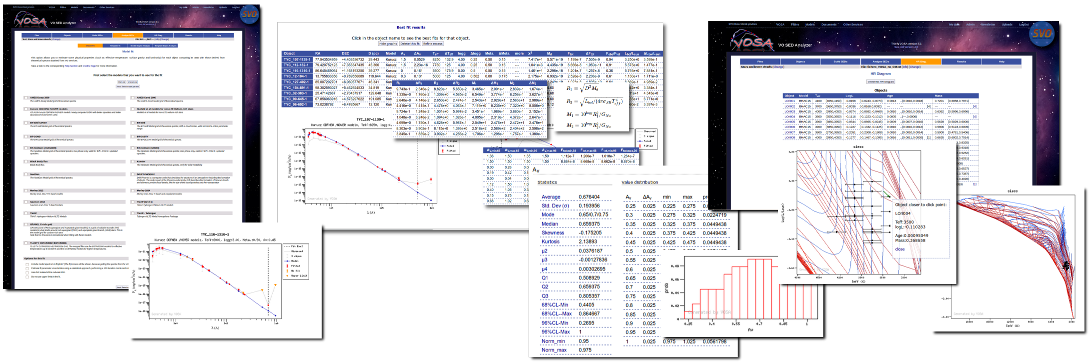

Figure 2: Chi-square fit, Bayesian analysis and HR diagram for stellar objects.

functions (PDFs) for each parameter of the grid of synthetic spectra. In this case, not only the most probable value is provided, but also all the statistics on the probability distribution.

In both methods, users have the option of considering the visual extinction as an additional fit parameter.

Currently, VOSA offers more than 20 different collections of models for different types of astrophysical objects: from brown dwarfs and planetary mass objects to massive and evolved stars. A suite of observational libraries covering the parameter space of late-type stars and brown dwarfs are also available.

After a fit process has been finished, sometimes it is useful to make small changes in the SED for some objects and repeat the fit. VOSA keeps track of what SEDs have been changed in a significant way after the fit, so that the current fit results could be not valid for those objects anymore. When the chi2 fit (or Bayes analysis) results are visualized again, VOSA gives the option to repeat the process only for those objects whose SED have been changed, but using the same models, options and parameter ranges used in the previous analysis and so that the fit results for the other objects remain the same. This is specially important when the user is working with large files, containing thousands of objects, but only a few of them have changed.

Once the best fit values for temperature and luminosity have been obtained, it is possible to build an HR diagram using isochrones and evolutionary tracks from VO services and VOSA performs linear interpolations to provide the user with estimates of masses and ages, and their respective confidence intervals.

4 Results

VOSA generates many results that can be visualized, downloaded in different formats (ascii tables, VOTables, png, eps, agr) or sent to other VO applications (like Topcat[4] or Aladin[5])

[4]http://www.star.bris.ac.uk/ mbt/topcat/

[5]http://aladin.u-strasbg.fr/

using SAMP [3].

A log file is also provided with a summary of all the activities done in VOSA for each input file. All the references to all the services that have been effectively used to obtain the results are also provided, both as a bibtex file and as a plain text explaining where each reference has been used.

5 Distributed architecture and asynchronous processes

The need of working with thousands of objects at the same time usually implies long calculation times and a heavy usage of the VOSA server capacities. Therefore we have redesigned VOSA to meet these needs.

Starting with version 5.0, in fact most VOSA calculations are not performed in-situ in the VOSA web-server. VOSA submits them to a different server and waits for the results. This dramatically reduces the load of the VOSA server, that is not longer affected by the number of jobs or the size of user files. In the future this infrastructure could be upgraded so that VOSA can distribute jobs among different servers to balance the load.

VOSA is designed to work with lists of objects and make mostly the same operations to all of them. We have upgraded VOSA to allow computation in a parallelized way, allowing that fits of different objects can be simultaneous instead of serialized one after another. The computation server organizes the jobs so that several of them are carried out simultaneously, and collects the results once all the jobs are finished.

VOSA communicates with the computation server in an asynchronous way. That is, VOSA submits a process and does not wait for it to finish. From time to time, or because a user requests it, VOSA checks the status of the process and, when it is finished, downloads the results, makes the final necessary processing and presents them to the user.

The main advantage of this capability is that the user does not need to wait, with the browser open, to the end of the process. Moreover, long queries are not affected by potential connectivity problems either. Users can start a process, close the computer and come back later to see how it is going. If it is finished, VOSA will show the results. If not, VOSA gives information on the status of the process and provides an estimate of the remaining time. Moreover, processes can be canceled at any time from the VOSA web interface.

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