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The POLLUX database of synthetic stellar spectra

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Abstract. The POLLUX database of theoretical stellar spectra includes high-resolution synthetic spectra in the optical range, and spectral distribution energies from the UV to the infrared domains. Data are produced using state-of-the-art codes for each spectral type. The aim of the POLLUX database is to offer easy and direct comparison to observational data, as well as to create easily accessed stellar libraries from M dwarfs or red supergiants to hot and massive stars including Wolf-Rayet stars. Here, we review the major steps of the elaboration of such a database : current status, ongoing and further developments.

`http://pollux.graal.univ-montp2.fr`

Keywords : astronomical data bases: miscellaneous – stars: fundamental parameters – methods: numerical – techniques: spectroscopic

1. Presentation and contents of the database

1.1 Presentation and aims

The POLLUX database of theoretical stellar spectra, developed at the University of Montpellier, intends to provide data offering a broad coverage in terms of stellar parameters (gravity *log g*, effective temperature T_{eff}, metallicity $[Fe/H]$ and various surface abundances). Two types of data are found in the POLLUX database : high resolution synthetic spectra (hereafter HRSS) and spectral energy distributions (hereafter SED).

The POLLUX database is designed to be useful to study stellar populations as a whole, as well as to facilitate the spectral synthesis for fundamental parameters and

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abundances determination of individual stars. It can also be used as a learning base for automated tools (MATISSE, DEGAS, ...), and to prepare ground-based and space missions.

Finally the POLLUX database can be used for teaching purposes concerning spectroscopy and stellar model atmospheres.

As of present, the database is accessible via a user-friendly web interface and is registered as a service compliant to the Simple Spectrum Access Protocol in the Virtual Observatory.

1.2 Contents

The POLLUX database contains both SEDs and HRSS. The content of the database as of January 2012 is described in Tab. 1. The coverage at solar metallicity is also displayed in Fig. 1. These data result from a workflow involving different codes according to the spectral domain considered. A detailed description of the codes and of the contents of the database can be found in Palacios et al. 2010 as well as in the user's guide of the database[1].

- O-type and Wolf-Rayet stars
  The data in this spectral type domain are computed combining model atmospheres computed with the code CMFGEN and synthetic spectra computed with the CMF_FLUX code. Both codes are described in Hillier & Miller (1998).
  CMFGEN generates non-LTE, line-blanketed 1D atmospheres models including stellar winds. This code also allows to treat the clumping in the wind of hot massive stars, and is suited to model the atmospheres of Wolf-Rayet stars.
  CMF_FLUX is a code solving the formal radiative transfer equation to yield a synthetic spectrum on the basis of the atmospheric structure obtained as an output of CMFGEN.
  The spectra of O-type and Wolf-Rayet stars in the database are not the result of a systematic grid computation (as is the case for the data associated to the other spectral types) and correspond to sets of parameters that follow stellar evolution tracks. Concerning the chemical abundances associated to these spectra, although the spectra are computed at solar metallicity, their content in C, N and O are non-solar as expected for stars undergoing strong winds.

- A- to F-type stars

  The data in this spectral type domain are computed combining model atmospheres computed with the code ATLAS12 (Kurucz 2005) on top of which the synthetic

[1] http://pollux.graal.univ-montp2.fr/USER%20GUIDE.pdf.

spectra are computed using the SYNSPEC code (Hubeny & Lanz 1992).
ATLAS12 allows computation of 1D plane-parallel hydrostatic and LTE model atmospheres. No molecules are included in the models used to compute the spectra in the POLLUX database, which justifies the lower end limitation of the temperature domain.
SYNSPEC is a program that provided an atmospheric structure input from ATLAS12 and a specific linelist, solves the LTE radiative transfer equation and produces a synthetic spectrum.
HRSS and SEDs are provided for the spectral types A and F with a regular sampling of the gravity ($\Delta log\ g$ = 0.5), effective temperature (ΔT_{eff} = 250 K) and metallicity domains (Δ [Fe/H] = 0.5 dex). The parameter space covered is described in Tab. 1.

- G to M-type stars The data in this spectral type domain are computed combining model atmospheres computed with the code MARCS (Gustafsson et al. 2008) on top of which the synthetic spectra are computed using the TURBOSPECTRUM code (Alvarez & Plez 1998).
MARCS provides LTE plane-parallel or spherical models including line-blanketing and convection. These models also include up-to-date molecular lists that are mandatory to produce realistic models of cool stars.
TURBOSPECTRUM uses MARCS models as input from which it computes a formal solution of the radiative transfer equation.

For cool stars, only high resolution synthetic spectra are available as of January 2012 in the POLLUX database. Up to now, the data presented as being SEDs that were proposed in POLLUX were actually just " statistical samples of the model surface fluxes derived in the model calculations, i.e., rough estimates of the surface fluxes that *should not be used* for synthetic photometry", as explicitly mentioned on the MARCS webpage. In order to ensure a homogeneous quality of the data provided, we are computing actual SEDs based on the MARCS model atmospheres that were used to generate the HRSS that are in the POLLUX database. We will thus be able in a forthcoming release to provide *for the first time* real SEDs for cool stars computed continuously over the spectral domain [910 Å, 200 000 Å], as the SEDs provided for O-type and A to F type stars.

1.3 Specificities

The POLLUX database is mostly fed with data that are not directly computed to this purpose but that are given by producers willing to share their models in a user-friendly, easy shared interface. These data are introduced in the POLLUX database provided that they comply resolution, wavelength and curation requirements. In particular a large amount of data concerning cool stars have been introduced in the database in

Table 1. Description of the data in the POLLUX database.

	G-M type	A to F type	O type	Wolf-Rayet
T_{eff} (K)	< 7000	[7000 , 15000]	≥ 25000	–
log g (dex)	-1.0 – 5.0	3.5 – 5.0	3.25 – 4.16	–
$\log_{10}$ ($L_*/L_\odot$)	1.188 – 5.977	–	4.8 – 6.07	5.3 – 5.9
HRSS Resolution[a]	> 150000	> 150000	150 000	150 000
SED λ domain[b] (Å)	910 - 200 000	910 - 20 000	50 - 200 000	50 - 200 000
Code atmosphere	MARCS	ATLAS12	CMFGEN	CMFGEN
Code spectrum	TURBOSPECTRUM	SYNSPEC	CMF_FLUX	CMF_FLUX
Number of HRSS	1558	396	33	11
Number of SEDs	–[c]	396	33	11

Notes: (a) spectra for A to M stars are computed with variable resolution $\frac{\Delta\lambda}{\lambda}$ but a constant wavelength step of 0.02 Å. The resolution of all SEDs is of 20 000; (b) the wavelength domain covered by HRSS is 3000 Åto 12 000 Å; (c) SEDs associated to the cool HRSS are under computation and will be soon available in the database.

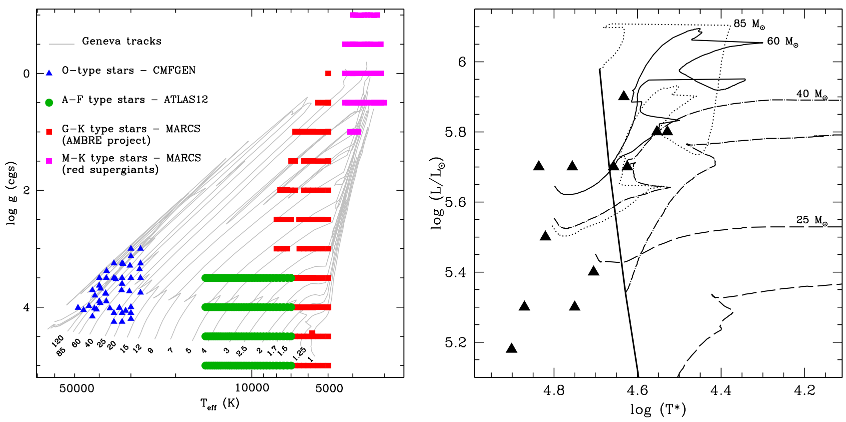

Figure 1. *Left* Coverage of the (Tefflog g) plane by the high resolution synthetic spectra available in the POLLUX database at solar metallicity (as of December 2011). Geneva stellar evolution tracks at Z = 0.02 with overshooting and normal mass loss from Schaller et al. (1992) are shown in grey. The masses, in solar mass units, are given on the plot. *Right* Wolf-Rayet data in the POLLUX database are represented as black triangles in an Hertzsprung-Russell diagram with T_* as abscissa (temperature at an optical depth τ = 20), along with rotating stellar evolution tracks from the Geneva database (Meynet & Maeder 2003).

2011. They have been computed by P. de Laverny et al. within the framework of the AMBRE project[2] that aims to provide all the stellar high and medium resolution spectra (from the FEROS, HARPS, UVES and FLAMES spectrographs) available

[2]Archéologie avec Matisse: aBondances dans les aRchives de lEso. http://www2.oca.eu/spip.php~article364

in the ESO archive with a science ready layer. This layer consists of fundamental stellar parameters and metallicity that are estimated using the MATISSE automated tool (Recio-Blanco et al. 2006). The high resolution synthetic spectra computed within this framework pave the MARCS model atmospheres grid as published in 2008 by Gustafsson et al., and served as a learning database for the MATISSE algorithm. Not provided in the ESO archives, these HRSS are distributed to the community in a user-friendly way via the POLLUX interface. The SEDs attached to these spectra are being computed (see above).

Another specificity of the POLLUX database is to provide Wolf-Rayet spectra and SEDs. Despite the small number of data for these specific objects, as can be seen from Fig. 1 (right panel), their distribution is noteworthy because it is unique.

2. Interface and interoperability

The POLLUX database is available to astronomers via two different channels. First via a user-friendly web interface that allows to select, visualize and retrieve the data and their dedicated description, and second via the virtual observatory registry through services handling the Simple Spectra Access Protocol. In this section we briefly present both access possibilities.

2.1 Web interface

The POLLUX web interface is accessible at the URL http://pollux.graal.univ-montp2.fr. The access to the entire database is open and no registration is needed to query nor to retrieve data. The high resolution spectra and SEDs are accessed through a dynamic query form where the user can choose the type of data (HRSS or SEDs), the spectral-type (through the code used, e.g. CMFGEN-WR, CMFGEN, ATLAS , MARCS) and the type of model atmospheres (e.g. plane-parallel or spherical). The query form is adapted according to this choice and the user can select a specific set of parameters. Once chosen, the result of query is another table with all the parameters which can be interrogated explicited and the possibility to : ***(a)*** view the header file containing describing the data, the methods and physics used to generate it as well as curation information, ***(b)*** view the spectrum[3] (or the SED) and super-impose several spectra (up to 3), ***(c)*** add all the results or only a selection to a retrieval basket, ***(d)*** directly download a spectrum in a simple flat table form. Arriving on the download form, the user can choose the format of the download, namely, flat table, fits or VOTable, and the type of archive (tar or zip file). These steps are shown in Fig. 2.

[3]If looking at a HRSS, the user can view the absolute flux or the normalized flux as a function of the wavelength.

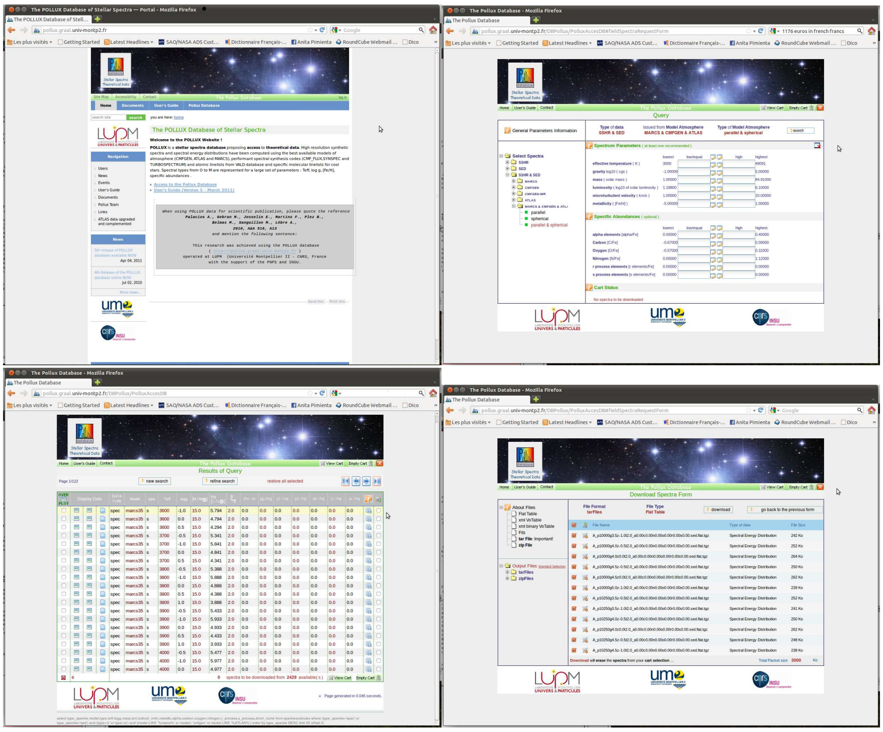

Figure 2. *Left to right up to down* Screen captures of the POLLUX webpage, showing the starting page, the query form, the result of query and the basket.

Also available on the POLLUX webpage is an up-to-date user guide and a selection of useful links, pointing in particular to similar databases.

2.2 POLLUX in the Virtual Observatory

The POLLUX database is designed to be compliant to the standards of the Virtual Observatory (hereafter VO). It is registered in the VO registries as a resource that can be queried using the Simple Spectrum Access Protocol (hereafter SSAP)[4]. This protocol is designed to primarily facilitate the access to *observed spectra*, and thus requires as *mandatory* fields the right ascension and declination of the object for which data are searched for. Theoretical spectra can not be queried that way since they do not represent any specific actual star but rather a template for a type of stars. It is thus needed for a POLLUX query to work within the VO, to use a modification of the SSAP that has been approved in the more recent recommendation document (version

[4] http://www.ivoa.net/Documents/SSA/

1.1). This consists in indicating to the service that makes a query to the POLLUX database that this database contains theoretical data by entering “METADATA” in the mandatory “FORMAT” field.

Although clearly documented in the description of the SSAP, this workaround solution is only understood by one service handling spectra : VOSpec. VOspec is a spectral analysis tool that is compatible with the SSAP. It only recognizes two-columns spectra in a set of pre-defined physical units, allows the plot and overplot of heterogeneous data (observations and/or synthetic data) retrieved among the resources available for SSAP queries as well as a number of mathematical operations. This tool is well suited for SED analysis, but does not allow a direct comparison between observed and synthetic spectra that have been normalized to the local continuum. The handling of the “dimensionless” unit cannot be forced which forbids at present a direct comparison between observed and synthetic spectra in VOspec, for fundamental parameters estimate for instance.

3. Example of use-case

In this section, we develop a typical use-case of the POLLUX database aiming at directly comparing an observed spectrum to a set of synthetic spectra within the database.

- Select and display the observed spectrum of a given object
- Normalized the flux to the local continuum if necessary
- Search in catalogs hosted in Vizier@CDS the spectral type and luminosity class and/or the fundamental parameters of the star
- Use this information to guide the query in the POLLUX database
- Retrieve the most adequate data in POLLUX
- Transform the POLLUX spectrum into a simulated observation by applying on-the-fly convolution (instrumental profile, rotational profile, macroturbulence profile)
- Overplot the set of simulated observations with the actual observed data for direct comparison.

As of January 2012, this use-case is partially possible as a workflow using VO protocols to communicate between the POLLUX database, a visualisation tool as VOSpec, SPLAT-VO or TOPCAT, and the Vizier database. The convolution module and a fully on-the-fly handling of the spectra for overplot using one of the aforementioned tools still need to be implemented and solved.

4. Future developments

Libraries of synthetic stellar spectra are useful *and used* for different astrophysical purposes, from stellar populations to individual stars studies. Ideally, complete wavelength and parameter space coverage is seeked within the same library, and in the case of data coming from heterogeneous sources, the detailed information on all physical and numerical ingredients used to generate the spectra as well as clear curation information are needed.

With the POLLUX database, we aim to ease the access, the diffusion and the distribution of synthetic spectra. We have already developed a user-friendly web interface to distribute heterogeneous data in a standardized way (same format, data model) for O-type and Wolf-Rayet stars, A and F type stars and G to M type stars. Thanks to its compatibility with VO services, the spectra and SEDs proposed in POLLUX should also be directly comparable to other theoretical data complying with the SSAP, or to observed spectra in telescope archives.

In order to enhance the visibility and use of the library in the POLLUX database, the next steps will be to complete the HR-diagram coverage (B stars, IR data), to provide SEDs for those sets of parameters for which only HRSS are available, and to provide a convolution applet/tool that will allow the transformation of the theoretical data into simulated observations.

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