POLLUX DATABASE – CONTENT & USER'S GUIDE

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Server Version 2.0 - DataBase Version v11 – March 2023

Contents

1 AIM

POLLUX is a database of stellar spectra developed at the Laboratoire Univers et Particules de Montpellier (LUPM - University of Montpellier - CNRS). Its aim is to provide a comprehensive library of theoretical stellar spectra with a broad coverage of the atmospheric parameters (effective temperature $T_{\rm eff}$, gravity $\log g$ and metallicity [Fe/H]) as well as spectral types across the Hertzsprung-Russell Diagram.

The POLLUX database collects and presents essentially synthetic spectra computed at high resolution (SSHR data). Some spectral energy distributions are also available only for the early spectral type models.
In the present version, which is the 11^{th} release, the database is made accessible via a renewed web interface.
The HRSS are available for spectral types from O to M and for several initial chemical compositions ([Fe/H] and [α/Fe]).

POLLUX spectra are expected to be useful to astrophysicists for stellar or galactic applications in several respects :

- abundance determinations
- accurate determination of fundamental properties of stars
- multi-wavelength coverage
- test for the current state-of-the-art model atmospheres
- stellar populations synthesis,
- as well as for teaching purposes oriented toward spectroscopy, model atmospheres, etc...

In its 11$^{\rm th}$ version available as of March 2023, POLLUX is made available on-line to the community via a new web page (`http://pollux.oreme.org`) regrouping a documentation, a retrieval interface for the data and an on-line graphic display tool. The web interface also offers the possibility to make the convolution of portions of the spectra via the SPECONVOL VO-service (`ivo://ov-gso/ssap/speconvol`), thus allowing the user to simulate an observation. The data can be retrieved in formats compliant to the Virtual Observatory standards (namely FITS and XML VOTable). The POLLUX database can also be accessed via the VizieR service at Centre de Données de Strasbourg (CDS). It is a registered service of the VO `ivo://ov-gso/ssap/pollux`.

Table 1: Description of the different collections available in the POLLUX DB as of March 2023

Collection	Radiative Transfer	Spectrum Synthesis	T_{eff}	Resolution	Spectral Range	Type	NLTE
AMBRE	MARCS[3]	TURBOSPECTRUM[4]	[3500 K - 8000 K]	> 150 000	VIS[†]	1–D	No
RSG	MARCS[3]	TURBOSPECTRUM[4]	[3300 K - 4500 K]	150 000	IR[◊]	1–D	No
BT-Dusty	PHOENIX[6]	PHOENIX[6]	[2000 K - 6000 K]	> 100 000	VIS[†]– IR[⊗]	1–D	Yes for atoms
STAGGER	STAGGER[7]	OPTIM3D[8]	[3899K – 7000 K]	20 000	UV – VIS – IR[‡]	3–D	No
STAGGER-INTENSITY	STAGGER[7]	OPTIM3D[8]	[3899K – 7000 K]	20 000	UV – VIS – IR[‡]	3–D	No
STAGGER-RVS	STAGGER[7]	OPTIM3D[8]	[3899K – 7000 K]	300 000	Gaia RVS[•]	3–D	No
CMFGEN	CMFGEN[5]	CMF-FLUX[5]	[12020 K - 63880 K]	150 000	UV – VIS – IR[*]	1–D	Yes
CMFGEN-WR[★]	CMFGEN[5]	CMF-FLUX[5]	[33780 K - 74300 K]	150 000	VIS[†]	1–D	Yes
CMFGEN-SED	CMFGEN[5]	CMF-FLUX[5]	[12020 K - 63880 K]	15 km.s^{-1}[⊘]	50 to 200 000 Å	1–D	Yes
CMFGEN-WR-SED[★]	CMFGEN[5]	CMF-FLUX[5]	[20638 K - 74300 K]	15 km.s^{-1}[⊘]	50 to 200 000 Å	1–D	Yes

3 Gustafsson et al. (1975, 2008) and Plez et al. (1992); see `https://marcs.oreme.org`
4 Alvarez & Plez (1998)
5 Hillier & Miller (1998); see also `http://kookaburra.phyast.pitt.edu/hillier/web/CMFGEN.htm`
6 Hauschildt, Baron & Allard (1997); see also `https://www.physik.uni-hamburg.de/en/hs/group-hauschildt/research/phoenix.html`
7 Magic et al. (2013); see also `https://staggergrid.wordpress.com/`
8 Chiavassa et al. (2009, 2018)
★ Wolf-Rayet models - The temperature of reference given in the fourth column is not T_{eff} in this case but $T_\star$ for these stars
† 3000 to 12000 Å
◊ 10000 to 50000 Å
* UV : 900 to 3000 Å; VIS : 3000 to 12500 Å(3000 to 12000 Å for low metallicity spectra); IR : 12000 to 25000 Å
⊗ VIS : 3000 to 12000 Å; IR : 12000 to 200000 Å
‡ UV : 2000 to 3000 Å; VIS : 3000 to 12000 Å; IR : 12000 to 200000 Å
• 8395 to 8905 Å
⊘ Resolution for SED given as a velocity resolution, the quoted value corresponding to the step in velocity.

2 SOURCES FOR THE THEORETICAL DATA

2.1 Radiative transfer and spectral synthesis codes

As of March 2023, the database gathers **20697** high (and medium) resolution synthetic spectra associated to spectral types O to M and to Wolf-Rayet stars and **245** spectral energy distributions for O-type and Wolf-Rayet stars.

Table 1 references the radiative transfer codes used to generate the model atmospheres and the associated spectrum synthesis programs used to compute the synthetic spectra actually available in the POLLUX database. It also provides the temperature domain covered by each collection, the spectral resolution of the spectra, the spectral range provided (UV, VIS or IR), the type of radiative transfer code used to compute the model atmosphere (1–D or 3–D) and information on the NLTE treatment of the radiative transfer (yes or no).

Geometrical effects are taken into account according to the spectral type and gravity, and the HRSS available in the database are derived from both spherical and plane-parallel models accordingly.

2.2 Atomic and Molecular data

Information on the atomic and molecular data used in the computation of the spectra are given in the header attached to each spectrum (see § 3.3).

- For the spectra of the RSG collection, with log g $\leq$ 1 dex and $T_{eff} < 4500$ K, the atomic linelists are taken from the VALD database (Kupka et al. 2000), and they are complemented by specific molecular linelists (Plez, private communication) for cool stars. A link is provided in the header with the detailed linelists (atomic and molecular) used in the computations.
- For the spectra of the AMBRE collection computed by P. de Laverny within the framework of the AMBRE project (de Laverny et al. 2012), the atomic linelists are taken from the Opacity Project database (Badnell et al. 2005, Seaton 2005 and references therein), and are complemented by specific molecular linelists.
- For the spectra of the CMFGEN and CMFGEN-WR collections, the atomic linelists are mainly taken from the Opacity Project database (Badnell et al. 2005, Seaton 2005 and references therein), and are occasionally complemented by specific linelists.
- For the spectra of the STAGGER, STAGGER-RVS and STAGGER-INTENSITY collections the molecular and atomic linelists are the same as the last version of the MARCS model atmospheres (see Gustafsson et al. 2008 and Chiavassa et al. 2018, `https://marcs.oreme.org`).
- For the spectra of the BT-Dusty collection, multiple molecular and atomic linelists are used that can be directly found in a companion file to each spectrum accessible via an URL directly from the header file or through a datalink for the users of the VO service (see below). All of the spectra currently in this collection use the Barber & Tennyson (2006) water vapour linelist. This file is the input file to the PHOENIX code originally labelled as ".spec.5" with the PHOENIX notation. Such files include all the setup information of each computation, and in particular the atomic and molecular linelists.

2.3 3–D models

Since the 9^{th} DB release, spectra based on 3D Radiative HydroDynamic simulations of stellar atmospheres performed with the STAGGER code (Magic et al. 2013) are distributed in POLLUX. These spectra are computed with the OPTIM3D code and result from a disk integration and a temporal average (Chiavassa et al. 2018). These spectra assume zero microturbulence, as this parameter is no longer needed in 3D RHD simulations, in which velocity fields are self-consistently accounted for. They are available through three collections (see Table 1) : medium resolution power and intensity spectra (constant resolving power of $\lambda/\Delta\lambda$ = 20 000) over a very large spectral range, from 2000 Å to 200 000 Å , high resolution spectra (constant resolving power of $\lambda/\Delta\lambda$ = 300 000) over the narrow spectral range of the Gaia-RVS , from 8395 to 8905 Å. In addition to the flux spectra averaged over the stellar surface that were previously available in the database, the intensity spectra at different inclination angles $\mu = cos\theta$, where θ is the angle with respect to the line of sight, are now also available in the present release[1].

2.4 PHOENIX models in memoriam Dr. France ALLARD†

Since the 10^{th} release of the POLLUX DB we propose PHOENIX stellar spectra specfically computed for this database by F. Allard†. They are gathered in a collection named ”BT-Dusty” which refers to models using the Barber & Tennyson (2006) water vapor linelist and in which dust is formed is equilibrium with the gas phase (maximum dust content). Such models are ”valid” for Near-IR studies with $T_{eff} > 1700$ K.
Compared to the models distributed on the personal webpage of F. Allard† (`https://perso.ens-lyon.fr/france.allard/indexfr.html`) and at the Lyon Data center for the Sciences of the Universe LyDU, the spectra available through POLLUX include both the absolute flux and **the flux normalized to the continuum**, as any other spectra in the POLLUX DB (see below). The normalised flux requires the knowledge of the continuum of the spectra, an information not available for the previous collections of PHOENIX spectra as distributed in the LyDU database and on F. Allard webpage. The continuum of the spectra in the BT-Dusty collection of the POLLUX database were computed following the procedure described in Kulenthirarajah et al. (2019), by using PHOENIX to compute the actual continuum for each spectrum. This is done by removing the discrete opacities, making any atomic and molecular data unavailable and by keeping dust and continuous opacities.

3 THE POLLUX DATABASE - LATEST RELEASE

Here we describe the data available within the database as of March 2023 in terms of actual files and coverage of the different parameters spaces. A count of the spectra available per spectral domain and collection is given in Table 3.

3.1 Updates of the latest release

- **New RSG spectra**
  The RSG spectra have been recomputed with the latest versions of MARCS and Turbospectrum codes, and are now available in the infrared spectral range. Optical spectra will be published in a following release.

[1] Ten different inclination angles are available in addition to the averaged spectra $\mu = cos(\theta) = [1.00, 0.90, 0.80, 0.70, 0.50, 0.30, 0.20, 0.10, 0.05, 0.01]$.

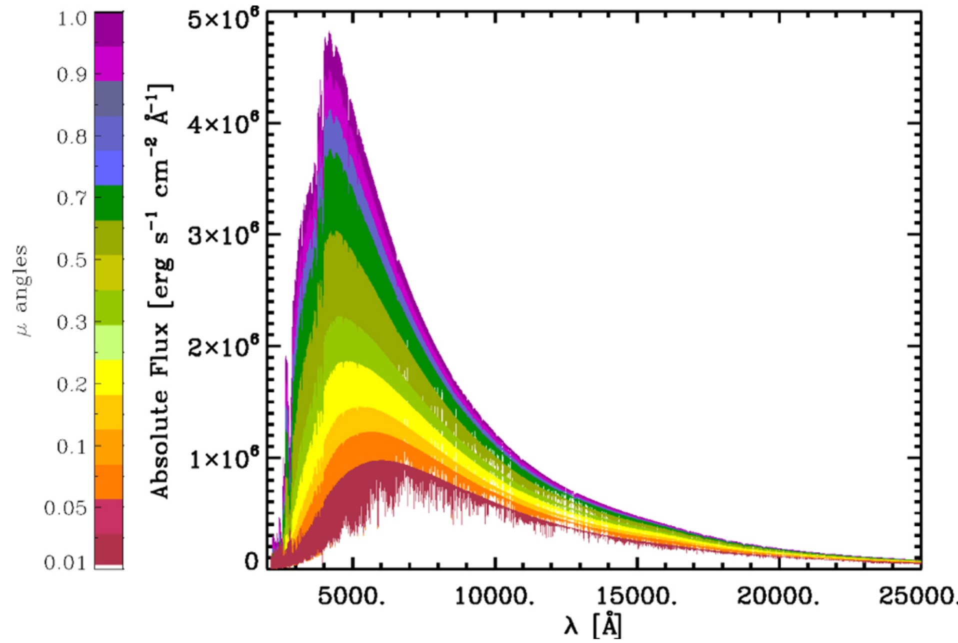


Figure 1: Synthetic spectra of the solar simulation in the spectral range 2000 – 25000 Åand for different $\mu = cos(\theta)$ inclination angles used in the computations of the spectra from the STAGGER-INTENSITY collections. *From Chiavassa et al. 2018, A& A 611, A11.*

- **Corrected metadata and new spectra in the CMFGEN collection**
  Inconsistencies between the metallicity and individual abundances were found for the CMF-GEN spectra and have been corrected. An additional set of spectra associated to very massive stars at low metallicity, and related to the paper by Martins & Palacios (2022) is also available.

- **ATLAS collection temporarily removed**
  THE ATLAS spectra remain unavailable as of March 2023. Corrected spectra have been computed and should be provided in the database during Summer 2023.

- **New STAGGER-OPTIM3D intensity spectra**
  New intensity spectra for different values of inclination angles ($\mu = cos(\theta)$, with θ the angle with the line of sight) as originally computed for Magic et al. (2013) and Chiavassa et al. (2018), are now also distributed in the POLLUX database in the STAGGER-INTENSITY collection. An illustration of the impact of the inclination angle on the intensity spectrum is given in Fig 1 extracted from Chiavassa et al. (2018).
  These new data are available for the spectra in the STAGGER and STAGGER-RVS collections.

3.2 The data : Synthetic Spectra and Spectral Energy Distributions

The high resolution synthetic spectra (hereafter HRSS) distributed consist of three columns files giving the wavelength, the absolute flux and the normalised flux in the first, second and third columns respectively.

All the spectra are available in the optical range between 3000 Å and 12000 Å, and for some collections additional spectral ranges (UV or IR) are also made available with a wavelength interval that may vary from one collection to the other (see Table 1).
The number of points in each spectrum is usually the same for all spectra belonging to a specific collection except for the BT-Dusty collection where each spectrum has a different number of points.

The resolution of the different spectra in the database is indicated in Table 1. Here are some specifications for the spectra that do not have a constant resolution :

- For the BT-Dusty collection, the spectral resolution varies as a function of the wavelength within each spectrum, and varies from one spectrum to another depending on the temperature with R ≥ 130 000.
- For the RSG and AMBRE collections, the resolution varies within the spectral domain considered, and it is characterised by a constant step in wavelength $\delta\lambda = 0.02$ Å, leading to R ≥ 150 000 for these data sets.

Since the 10^{th} release of the POLLUX database, Spectral Energy Distributions for Wolf-Rayet, O and B-type stars from the CMFGEN collection are made available. The 245 SED derived from CMFGEN model atmospheres cover the following wavelength range $\lambda \in [50; 200000]$ Å with a resolution R = 10 000.. The spectral energy distributions are available in the form of a two column file giving the wavelength and the absolute flux as the first and second columns respectively.

Figures 2 and 3 show the adopted nomenclature for the data in POLLUX. Each name includes information about temperature, surface gravity, metallicity and chemical composition, as well as on the geometry of the model atmosphere and specific variable related to the model atmosphere computation (microturbulent velocity, mass loss or parameters of the wind), as well as the specification of the spectral domain it encompasses.

Table 2: Collections and corresponding prefixes in the adopted nomenclature

Collection	Prefix
AMBRE	M
RSG	M
CMFGEN	C
CMFGEN-WR	CWR
BT-Dusty	P
STAGGER	O
STAGGER-RVS	G
STAGGER-INTENSITY	O

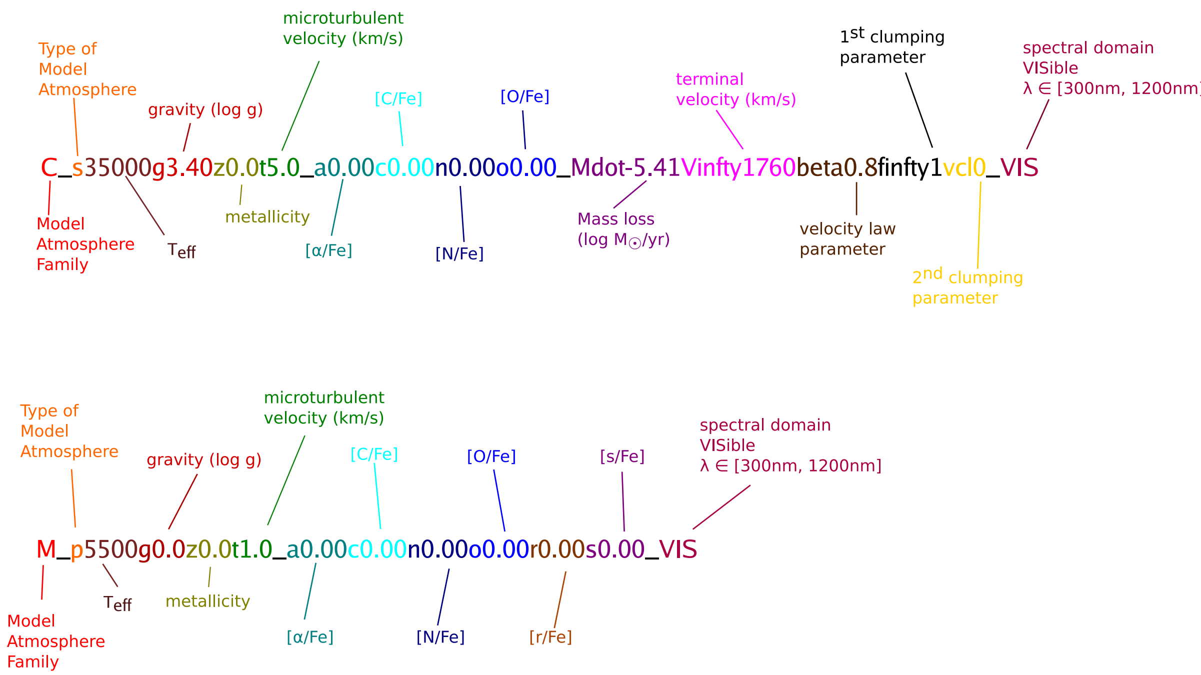


Figure 2: Name nomenclature for the CMFGEN (upper line) and AMBRE,RSG or BT-Dusty (lower line) files. The spectra are given the extension **.spec** and the associated headers have **.spec.txt**.

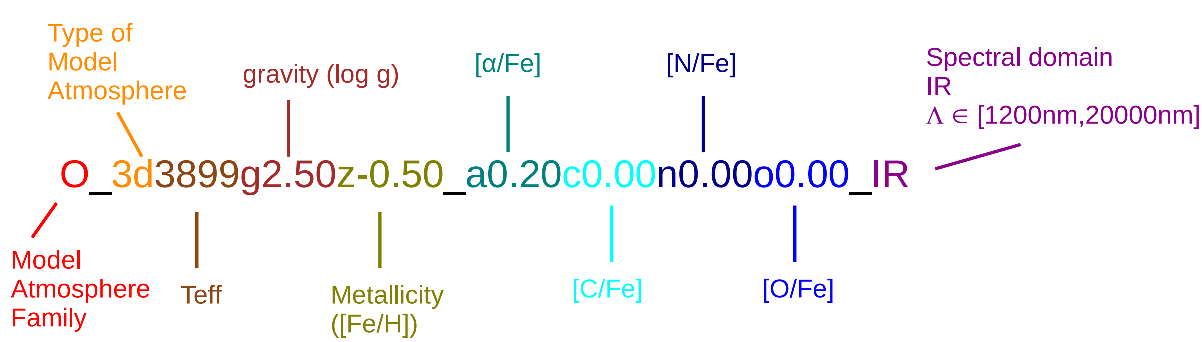


Figure 3: Name nomenclature for the files in the STAGGER collection.

Finally the size of uncompressed individual high resolution synthetic spectra in ASCII format is given in Table 3 according to the collection and the spectral domain.

Table 3: Typical size of uncompressed HRSS ASCII files and Number of spectra for the different collections and spectral domains.

Collection	Spectral Domain	Size	Number of spectra
AMBRE	VIS	15.3 MB	12927
RSG	IR	10 MB	40
CMFGEN	IR	2.2 MB	309
CMFGEN	VIS	5.2 MB	309
CMFGEN	UV	1.6 MB	309
CMFGEN-WR	VIS	5.8 MB	11
BT-Dusty	IR	18 to 20 MB	377
BT-Dusty	VIS	14 to 22 MB	377
STAGGER	IR	2.1 MB	181
STAGGER	VIS	1 MB	181
STAGGER	UV	300 kB	181
STAGGER-INTENSITY	IR	2.7 MB	1791
STAGGER-INTENSITY	VIS	1.3 MB	1791
STAGGER-INTENSITY	UV	420 kB	1791
STAGGER-RVS	VIS	655 kB	122

3.3 The Data Model : Header files

Each spectrum can be seen as the result of a workflow as shown in Fig. 4 (codes, input physics, physical parameters characterising the spectrum, ...).

A header file describing the data itself and all the relevant ingredients used within the workfow that lead to the synthetic spectrum or the SED is attached to each dataset. In addition to this information, the header file also contains a set of descriptors characterising stellar spectra which are independent of whether the data is observed or synthetic (file structure and curation[2] information). It also provides the original ownership of the associated spectrum.

Finally, a tag describing the detailed specifications of the spectrum that are not clearly seen from the header file is introduced, and it is used to give an appreciation of the pertinence. This tag, named ”specs”, appears in the form of a 8 digit number to be read as described in Table 4.

[2]Curation includes all information concerning the data sets that ensures they are available for discovery and re-use in the future. Number version of the code, data producer, date of production are part of the curation information.

Table 4: Description of the specs tag in the header file and the database

Digit number	Description	Possible values
1	Winds accounted for in model atmosphere	0 = No 1 = Yes 9 = Irrelevant
2	Equality of chemical compositions for model atmosphere (code1) and synthetic spectrum (code2) ⋆	0 = No 1 = Yes 9 = Irrelevant
3	Clouds accounted for in model atmosphere•	0 = No 1 = Yes 9 = Irrelevant
4	Narrow spectral domain †	0 = No 1 = Yes 9 = Irrelevant
5	Dust condensation in equilibrium with gas phase •	0 = No 1 = Yes 9 = Irrelevant
6	Full cloud model including nucleation, growth sedimentation and mixing in addition to condensation•	0 = No 1 = Yes 9 = Irrelevant
7	Model limitation ⋄	0 = No 1 = Yes
8	Pertinence . Indicates whether the spectrum should be used under certain restrictions or not ‡	1 = All applications 2 = Restricted applications

⋆ Some MARCS HRSS from the AMBRE project have inconsistent [α/Fe] valued between the model atmospheres and the synthetic spectra (see de Laverny et al. 2012 for details), and are flagged with pertinence = 2. They are represented as black squares in the Fig 6.

• These flags concern PHOENIX models and describe the physics of the spectra in the BT-Dusty collection.

† This presently concerns the OPTIM3D HRSS from the STAGGER-RVS collection, are available only for a narrow portion of the visible domain. These spectra were attributed pertinence = 2.

⋄ This relates to limitations in the model atmosphere (code1) or the synthetic spectrum (code 2). In the present version of the database, this flag is set to 1 for the coolest spectra of the AMBRE collection ($T_{eff} \in [3500\ K; 4500\ K]$) for which caution is caution is advised in de Laverny et al. (2012) and Gustafsson et al. (2008).

‡ All spectra that are flagged with 0 for the 2^{nd} digit, 1 for the 4^{th} digit or 1 for the 7^{th} digit have been attributed pertinence = 2, meaning they are suited for restricted uses only or to be used with caution.

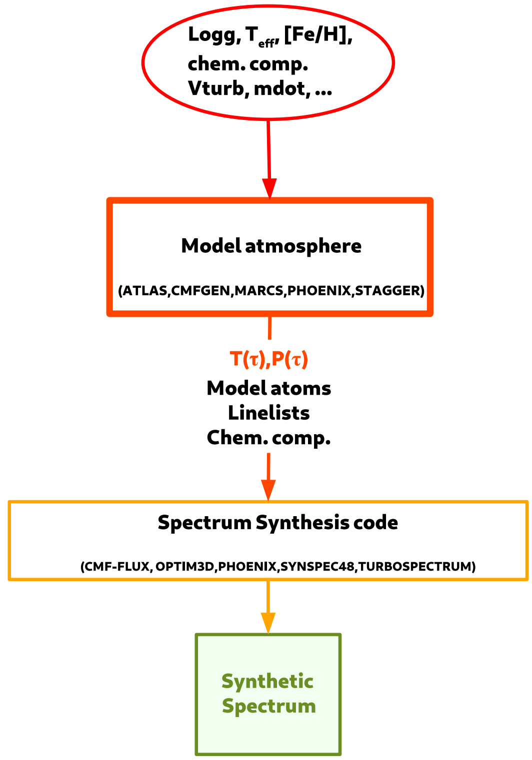


Figure 4: Illustration of the workflow leading to the production of a synthetic spectrum (simpler case of the 1–D model atmospheres).

3.4 VO compliancy

The data provided in the POLLUX database have been made compliant to the Virtual Observatory standards.

POLLUX is accessible via the Simple Spectra Access Protocol Version 1.1, the description of which can be found at this URL `http://www.ivoa.net/Documents/latest/SSA.html`. This means in particular that all the relevant characteristics of the data appearing in the query forms described above have an associated UCD+1 (Unified Content Descriptors, Version 1+, see `http://www.ivoa.net/Documents/latest/UCD.html`) that allows for interoperability within the VO.

The POLLUX database is registered in the EURO-VO registry as a service providing theoretical spectra. The query to the registry allows POLLUX data to be visible through VO tools such as CASSIS (`http://cassis.irap.omp.eu/`), VOSpec (`https://www.cosmos.esa.int/web/esdc/vospec`) and Aladin (`http://aladin.u-strasbg.fr/`).

Since the 3rd release, the HRSS files (data + header) may be retrieved in the VO compliant formats

XML VOTable, XML binary VOTable and FITS (see below). These versions of the data have been generated via the TOPCAT VO tool (http://www.star.bristol.ac.uk/~mbt/topcat/).

Since the 7th release, POLLUX can be used through the VO within the framework of Science Cases. In particular, we have developed the science case SPECFLOW (http://specflow.oreme.org) that combines the query of Vizier and Simbad CDS services, the observational database Polarbase, the POLLUX database and the spectral convolution service SPECONVOL registered in the VO (ivo://ov-gso/ssap/speconvol), included in the POLLUX web interface as described above and declared in a DATALINK adhoc service.
Since this 10th release, POLLUX provides the availability of a file containing all the lines used for BT-Dusty spectra via a service declared in a DATALINK adhoc service.

POLLUX is also accessible via the Simulation Data Access Layer (SimDAL) and the Provenance Simple Access Protocol (ProvSAP). At the moment, these two protocols are not used very often because there is still no VO tool that implements them.

3.5 Coverage of the parameters space

The POLLUX database includes solar metallicity data for O to M type stars. Spectra are available in the metallicity range -5.0 dex ≤ [Fe/H] ≤ 1.0 dex for A to K type stars (MARCS/Turbospectrum models and OPTIM3D models).

Concerning cool and hot stars, 1D HRSS with non-solar C,N,O abundances are also provided.

Table 5 summarizes the coverage of the fundamental parameters for the different collections available in POLLUX. The newly available data as of the present 11^{th} release are highlighted in red. On the other hand, Figures (5) to (8) illustrate the coverage in the Kiel diagram (T_{eff}, $\log g$) of the spectra in different collections.

Table 5: Coverage of the parameter space of the POLLUX DB as of March 2023

Collection	T_{eff} (step) [K]	$\log g$ (step)	[M/H]•(step)	[α/Fe] (step)	X	Y
AMBRE	3500 – 4900 (200)★ 5000 – 8000 (250)★	0 – 5.5 (0.5)	-5.0 – 1.0 (see Fig 6)	-0.4 – 0.8 (see Fig 6)	–	–
RSG	2300 – 4500 (100)	-1.0 – 1.0 (0.5)	0.0	0.0	–	–
CMFGEN	12020 – 63880 (⋄)	2 – 4.51 (⋄)	-1.48 [1]; -0.73 [1]; 0.0 [2] 0.04; 0.05	0.0	–	–
CMFGEN-WR	33780 – 74300 (∅)	0.0	-1.0 – 1.0 (0.5)	0.0	0.0 – 0.55⋄	0.38 – 0.99⋄
BT-Dusty	2000 – 6000 (100)	0.5 – 5.5 (0.5)	0.0	0.0	–	–
STAGGER	3899 – 7000 (≈ 500)	1.5 – 5 (0.5)	-4.0 – 0.5 (voir Fig. 8)	0.4; 0.2; 0.0 *	–	–
STAGGER-RVS	3899 – 7000 (≈ 500)	1.5 – 5 (0.5)	-2.0 – 0.5 (voir Fig. 8)	0.4; 0.2; 0.0 *	–	–

[1] Data at Z = 1/5 $Z_\odot$ and Z = 1/30 $Z_\odot$ published in Martins & Palacios (2020) and in Martins & Palacios (2022)
[2] Data at Z = $Z_\odot$ published in Martins & Palacios (2017)
★ The effective temperature step is of 200 K for T_{eff} ≤ 3900 K and of 250 K for hotter models.
• Also referred as [Fe/H] in most cases.
⋄ Irregular stepping. The spectra are computed along evolutionary tracks of massive stars as can be seen from Fig. (5).
∅ The temperatures given here are $T_\star$, i.e. temperatures at optical depth τ = 20, which is the relevant scale for Wolf-Rayet stars. Irregular stepping. The spectra are computed along evolutionary tracks of massive stars as can be seen from Fig. (7).
* α-elements are enhanced for subsolar metallicities with $[\alpha/Fe]$ = +0.2 dex for [Fe/H] = -0.5 dex and $[\alpha/Fe]$ = +0.4 dex for lower values of [Fe/H].

3.6 Overlapping regions

PHOENIX-based collections (BT-Dusty) and MARCS-based collections (AMBRE and RSG) overlap at solar metallicity in different regions of the Kiehl diagram. It is the case of spectra for G and K spectral type dwarf stars (see Fig. 9a, and for the spectra of K and M supergiants.

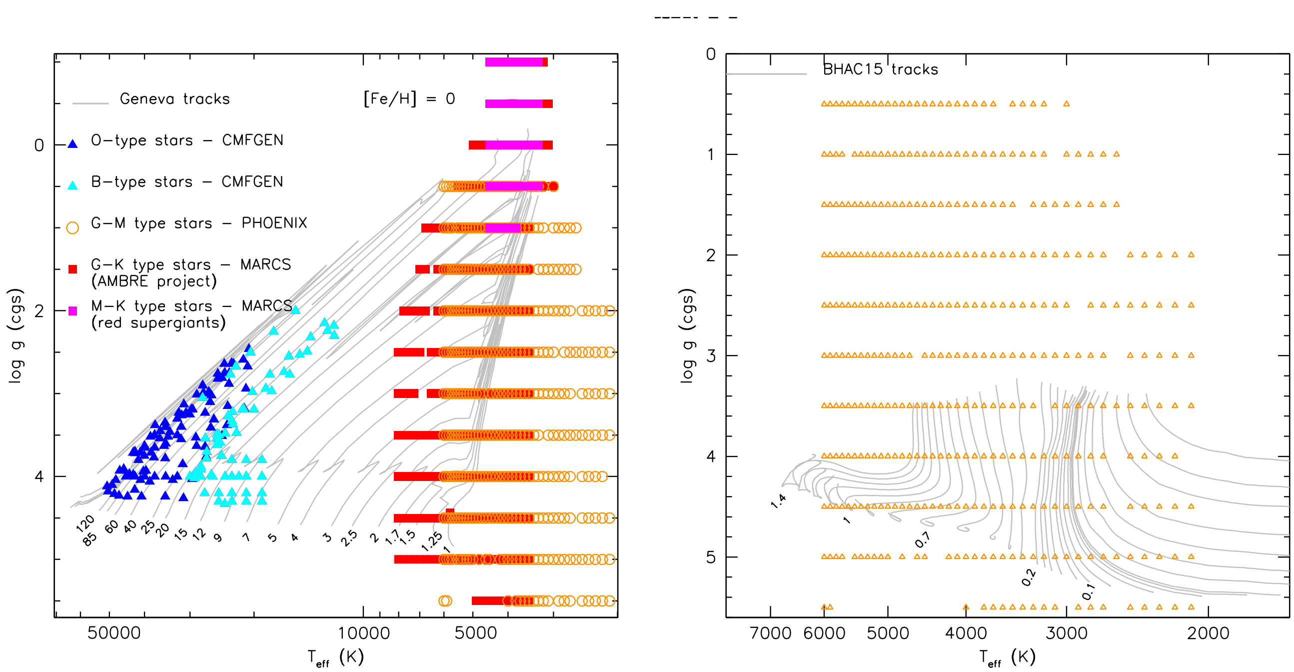


Figure 5: Coverage of the Kiel diagram (T_{eff} - $\log g$) plane by the HRSS associated with *(left)* CMFGEN (blue and cyan triangles), PHOENIX (orange circles dots) and MARCS (red and magenta squares) model atmospheres, and *(right)* PHOENIX BT-Dusty model atmospheres as of March 2023 for solar metallicity. Superimposed are standard stellar evolution tracks from the Geneva code (Schaller et al. 1992) on the left, and from Baraffe et al. (2015) on the right.

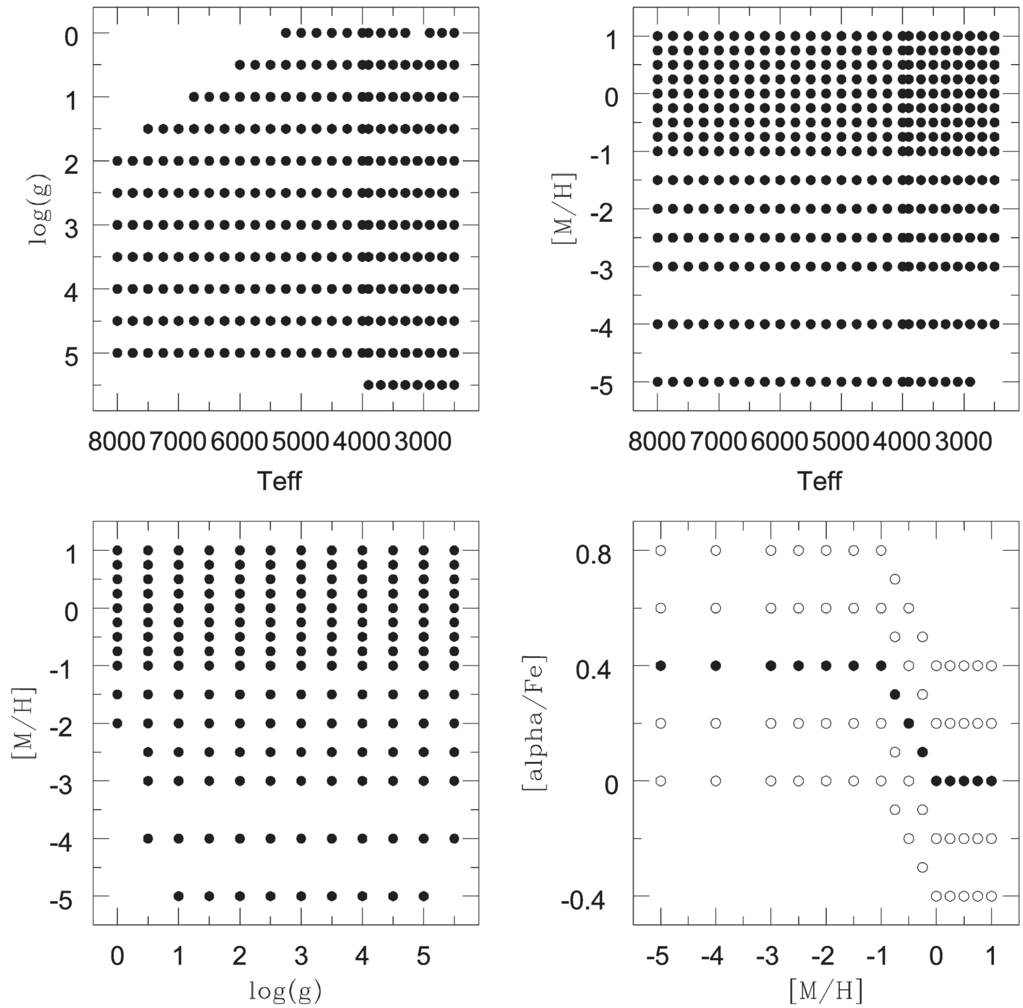


Figure 6: Distribution of the AMBRE synthetic spectra grid in the atmospheric parameters and [α/Fe] space. Only one value of [α/Fe]for every [M/H] was adopted during the model atmosphere selection process. This is illustrated in the bottom right panel where the AMBRE spectra computed from MARCS models with consistent [α/Fe] ratios are plotted with filled circles while open circles refer to all the other AMBRE spectra computed with atmosphere models that have inconsistent [α/Fe] ratios. These last ones are flagged with a pertinence = 2 in the POLLUX Database .*From de Laverny et al. (2012), A& A 544, A126.*

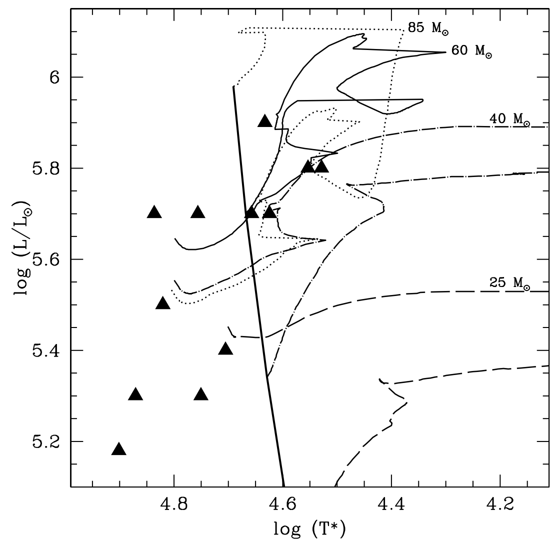


Figure 7: Coverage of the (T_{eff} - L) plane by the HRSS associated with CMFGEN model atmospheres Wolf-Rayet stars. The overplotted tracks are stellar evolution models including rotation from Meynet & Maeder (2003) for different initial masses as labelled (dotted lines for M_{ini} = 85 $M_{\odot}$, solid lines for M_{ini} = 60 $M_{\odot}$, dot-dashed lines for M_{ini} = 40 $M_{\odot}$ and dashed lines for M_{ini} = 25 $M_{\odot}$).

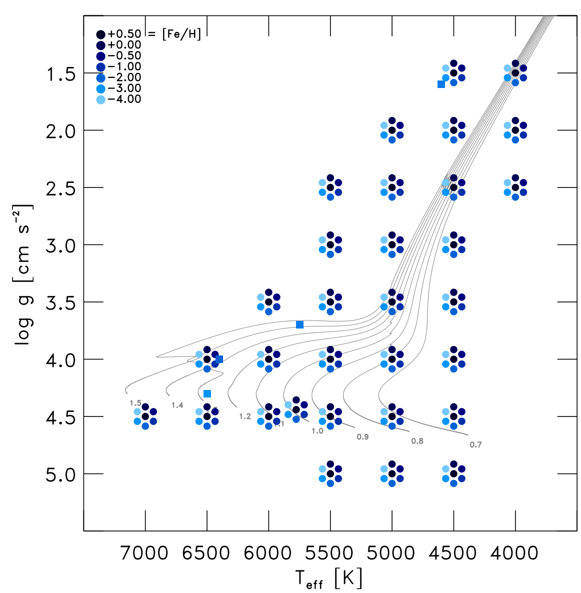


Figure 8: Kiel diagram showing the coverage of the STAGGER grid on which STAGGER and STAGGER-RVS collections are based. *From Magic et al. 2013, A& A 557, A26.*

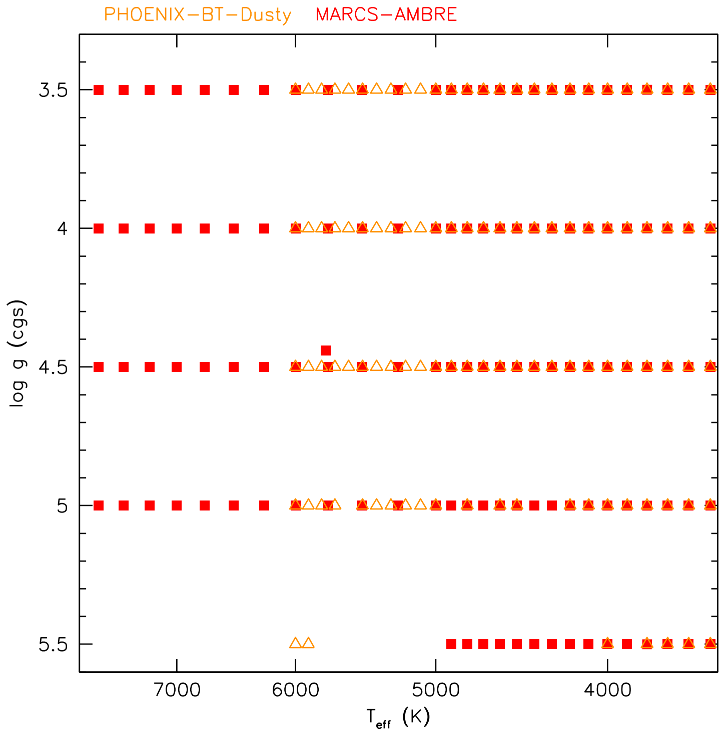


Figure 9: Illustration of the overlapping region of BT-Dusty and AMBRE collections at solar metallicity.

The spectra may differ in these regions due to the use of different ingredients in the computation of the model atmosphere, the synthetic spectrum or both (different input parameters, different linelists, ...).
We illustrate the overlap of the BT-Dusty, AMBRE and STAGGER collections for a solar-like star at solar metallicity in Fig. 10. The parameters used in each case are recalled in Table. 6.
Figure 10 shows the comparison between BT-Dusty, AMBRE and STAGGER-RVS (for the RVS domain only) high resolution spectra normalized to the continuum in the full optical domain, in the Gaia-RVS domain as well as in the region of the Hβ atomic line @ 4861 Å and of the CH line @ 4300 Å.

Table 6: Parameters of the solar-type spectra

Model	T_{eff}	log g	ξ	geom.	Abundances
AMBRE	5500 K	4.5	1 $km.s^{-1}$	p	GAS2007†
BT Dusty	5500 K	4.5	0.86 $km.s^{-1}$	s	CIFIST11‡
STAGGER-RVS	5530 K	4.5	irr.	3D	GAS2007

† Grevesse et al.(2007)
‡ Caffau et al. (2011)

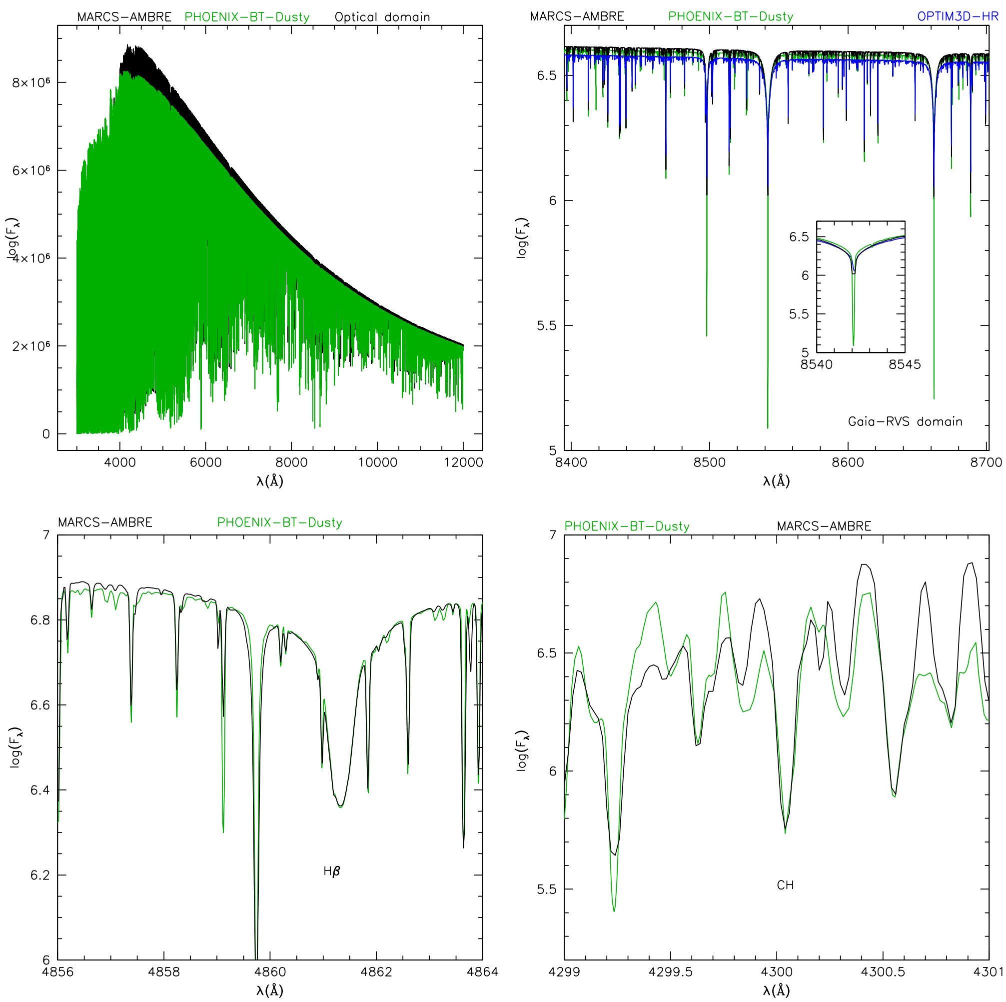


Figure 10: Overplot of spectra from the BT-Dusty (green), AMBRE (black) and STAGGER-RVS (blue) collections at T_{eff} = 5500K, $\log g$ = 4.5 and [Fe/H] = 0. The wavelength are given in the air and the ordinate presents the logarithm of the absolute fluxes.

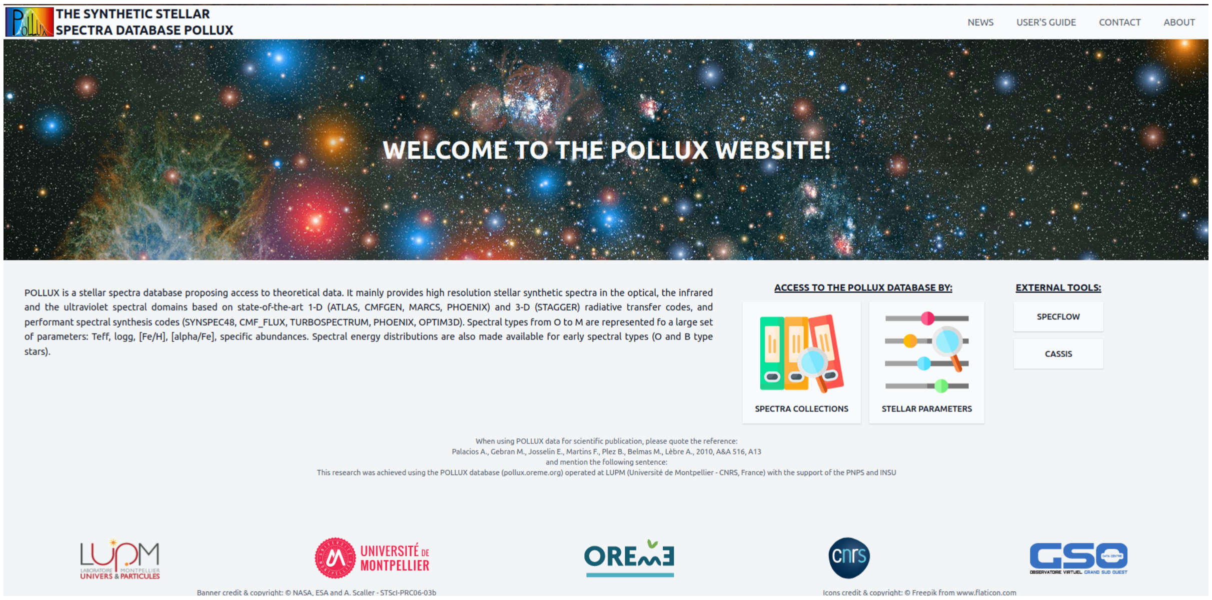


Figure 11: Pollux homepage.

4 HOW TO USE

The POLLUX database is accessible via the URL: `http://pollux.oreme.org`.

The web page and the database have been completely revisited, from a system based on Plone to a new database and web interface built using Django and Python languages. The web page is designed to be user friendly, and to allow inexperienced users to easily access, visualise and retrieve the data.

The homepage allows to access the database via two methods : 1) explore the different collections which correspond to ensembles of spectra generated using the same radiative transfer and spectral synthesis codes; or 2) query the stellar parameters. This organisation is new in the current version of POLLUX and is meant to facilitate the exploration and query.
From the homepage, the user can also access the news, this user's guide, read more about the people involved in the project and contact the managers via a contact form. Finally, direct access to the companion tools and databases SPECFLOW and CASSIS are also provided.

4.1 Collection Query Interface

In the present release and new web interface, the spectra and SEDs have been separated into collections associated with either a project or a publication (STAGGER-RVS, AMBRE), a type of objects (RSG, CMFGEN-WR) or a suite of radiative transfer and spectral synthesis codes (CMFGEN, BT-Dusty, STAGGER). Each collection is presented in this page (see Fig. 12) in terms of codes used, stellar parameters covered, number of spectra/SEDs available. The data producer is also emphasized and in some cases, reference papers are also given.

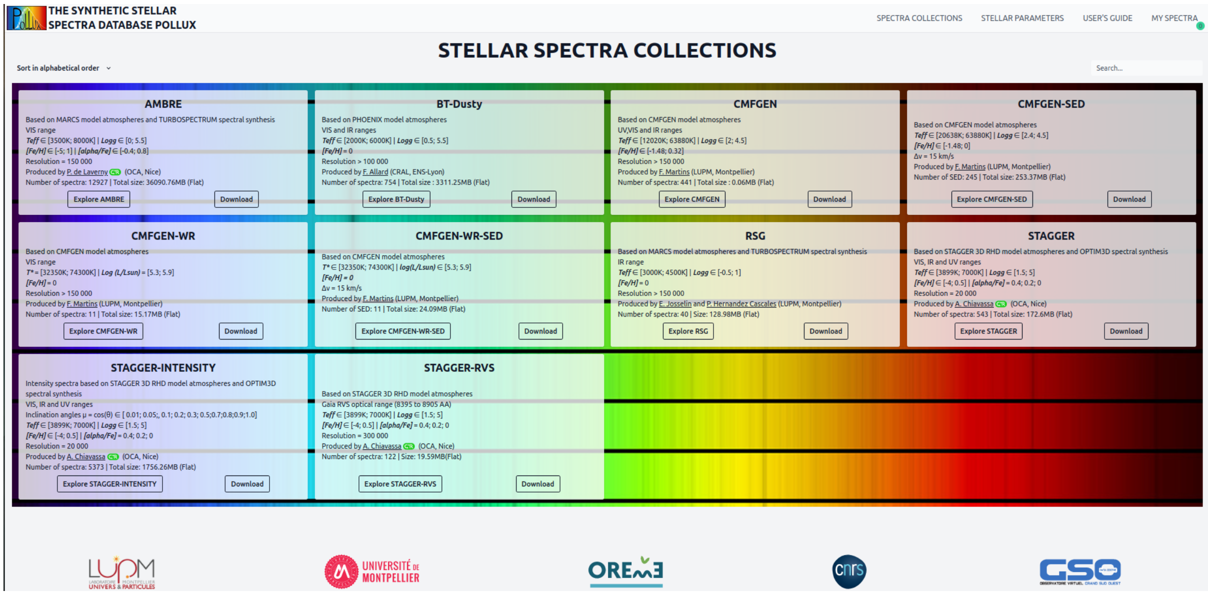


Figure 12: POLLUX Collection Query Interface.

From this page, the user may either retrieve the entire collection as an archive file (the size of which is given as the total size of the collection), or explore the collection.
In the second case, the user will access the stellar parameter query interface (described hereafter) that is also directly accessible from the homepage, with a pre-selected query tree for the collection that was chosen.

4.2 Stellar Parameters Query Interface

4.2.1 Query of synthetic spectra

This query is hierarchical and the parameters that can be queried in the right part of the page are adjusted according to the choice of spectra type, collection, spectral domain, and model type made in the left part of the query page.
The default display depends on the access path to this page. If coming from the homepage of POLLUX, all synthetic spectra are selected for query except WR spectra for which there is a special query interface, as shown in Fig. 13. If coming from a collection, the General parameters are already preselected to limit the query to this selected (see Fig 14).

The choice of the **General Parameters** on the left is made by clicking on the relevant boxes. The selected boxes appear in green. The selections are automatically exclusive : for instance, if the AMBRE collection is the only one selected, the boxes Synthetic Spectra, VIS, Plane-Parallel and Spherical will be automatically selected while all the others remain white (can still be selected) or grey (incompatible with the currently selected collection) as illustrated in Fig 14.

The user can specify the **Spectra Variables**. The possible query depends on the selected **General Parameters** that has been chosen :

Figure 13: POLLUX Stellar Parameter Specific Query Interface.

Figure 14: Example of exclusive query.

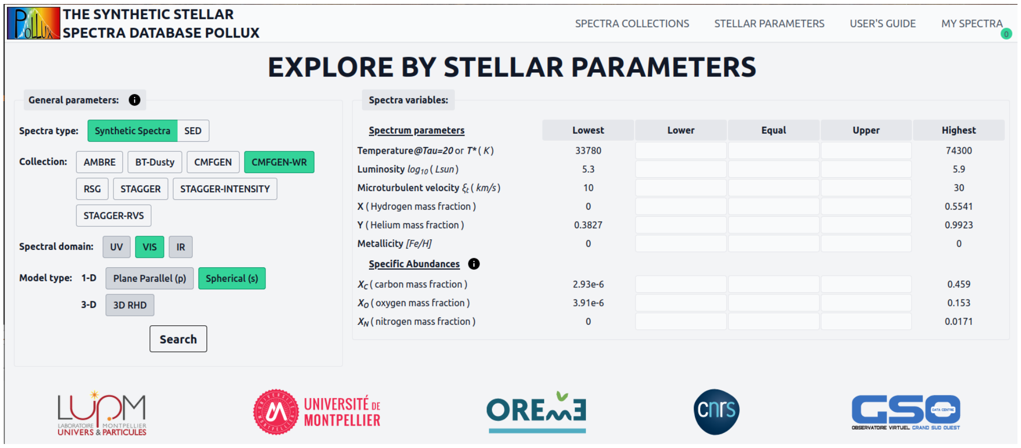


Figure 15: Query form for spectra in the CMFGEN-WR collection

- effective temperature
- log g
- mass (*appears only when spherical models are selected*)
- luminosity (*appears only when spherical models are selected*)
- micro-turbulent velocity
- metallicity [Fe/H]

When selecting the CMFGEN-WR collection, a specific query form will appear (as shown in Fig. 15) in which the parameters that can be queried are different :

- temperature at optical depth $\tau = 20$ T^*
- luminosity
- micro-turbulent velocity
- hydrogen mass fraction X
- helium mass fraction Y
- metallicity [Fe/H]

The user can either choose an interval or choose an exact value for the **Spectra Parameters**. The extremum values for each parameter in the selected spectra are also given.
A second query block is also available, which enables the user to choose data sets with **Specific Abundances**. The set of searchable abundances depends on the data queried. For CMFGEN and STAGGER data, queries can be made on Carbon, Nitrogen, Oxygen and α-elements in terms of [X/Fe]. For the AMBRE data, r- and s- elements abundances in terms of [X/Fe] can also be queried. For CMFGEN-WR data, the searchable abundances are Carbon, Nitrogen and Oxygen in terms of

mass fractions X_C, X_N and X_O.

Once the choices made, the request is sent by clicking on the Search button below the list of **General Parameters** on the left.

- If the exact value requested is not available in the database, a "no spectra" message will be returned.
- If the values queried exist, the spectra complying with the query will be displayed in the lower part of the window.
- If no value is entered in the **Spectra Parameters** fields, all the models complying with the selected **General parameters** will be displayed in the lower part of the window.

4.2.2 Query of spectral energy distributions

The query of form fro SEDs, currently only available for CMFGEN data, is similar to that of synthetic spectra as shown in Fig. 16.

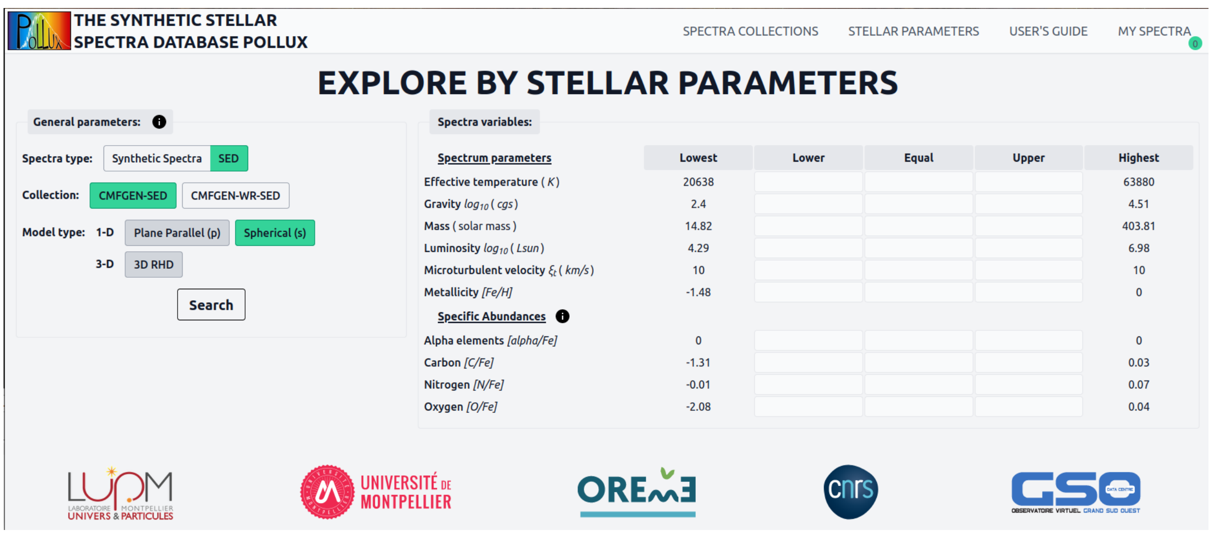
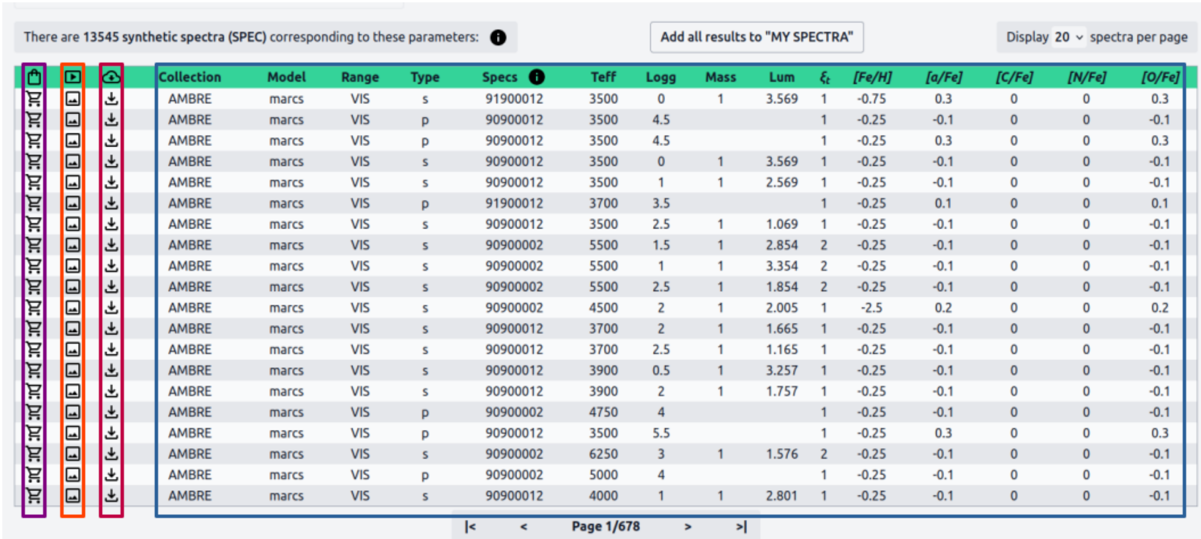


Figure 16: Query form for SEDs.

4.3 Results of Request

The result of the request is displayed on the lower part of the query page and consists of a table (dispatched on several pages if needed) containing 4 main parts : **Cart**, **Display**, **Download** and **Data Characteristics** as illustrated in Figure 17.
The table may be sorted according to a specific field by clicking on the column name.



There are 13545 synthetic spectra (SPEC) corresponding to these parameters:

Add all results to "MY SPECTRA"

Display 20 spectra per page

Collection	Model	Range	Type	Specs	Teff	Logg	Mass	Lum	ξ_t	[Fe/H]	[a/Fe]	[C/Fe]	[N/Fe]	[O/Fe]
AMBRE	marcs	VIS	s	91900012	3500	0	1	3.569	1	-0.75	0.3	0	0	0.3
AMBRE	marcs	VIS	p	90900012	3500	4.5			1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	p	90900012	3500	4.5			1	-0.25	0.3	0	0	0.3
AMBRE	marcs	VIS	s	90900012	3500	0	1	3.569	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900012	3500	1	1	2.569	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	p	91900012	3700	3.5			1	-0.25	0.1	0	0	0.1
AMBRE	marcs	VIS	s	90900012	3500	2.5	1	1.069	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900002	5500	1.5	1	2.854	2	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900002	5500	1	1	3.354	2	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900002	5500	2.5	1	1.854	2	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900002	4500	2	1	2.005	1	-2.5	0.2	0	0	0.2
AMBRE	marcs	VIS	s	90900012	3700	2	1	1.665	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900012	3700	2.5	1	1.165	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900012	3900	0.5	1	3.257	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900012	3900	2	1	1.757	1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	p	90900002	4750	4			1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	p	90900012	3500	5.5			1	-0.25	0.3	0	0	0.3
AMBRE	marcs	VIS	s	90900002	6250	3	1	1.576	2	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	p	90900002	5000	4			1	-0.25	-0.1	0	0	-0.1
AMBRE	marcs	VIS	s	90900012	4000	1	1	2.801	1	-0.25	-0.1	0	0	-0.1

|< < Page 1/678 > >|

Figure 17: POLLUX Result of Request for synthetic spectra. The first column allows to upload all or selected spectra into the " MY SPECTRA" space; the second column allows to display the spectrum and its header; the third column allows to directly download the selected spectra; the remaining columns give the attributes of the spectra retrieved in terms of General and spectra parameters.

The number of synthetic spectra found and the number of pages are also indicated. The User may also change the number of spectra displayed per page, and add all the results to the " MY SPECTRA" workspace that is also accessible via the top menu of the query page.

4.3.1 Cart, Display and Download

The three first columns of the query result correspond to the cart, the display and download of the spectra:

1. The first column of the query result allows to store the selected spectra into the workspace from which further visualization, process and download is possible (see below).
   When clicking on the empty cart icon, the icon will change to to indicate that the selected item has been uploaded to the "MY SPECTRA" workspace [3]. On the top menu of the page, the "MY SPECTRA" section will indicate the number of spectra that are available in the workspace, as illustrated in Fig. 18.

[3]This operation can be reverted by clicking again on the icon which will change to the , and remove the spectrum from the MY SPECTRA workspace.

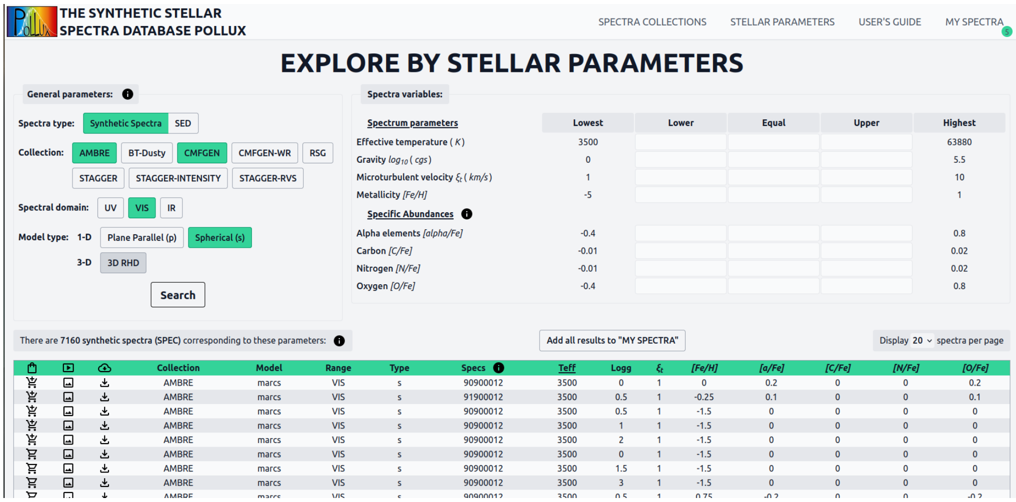


Figure 18: Example selected spectra uploaded in the "MY SPECTRA" workspace as seen from the query page.

2. ▶ The second column of the query result provides access to a new window by clicking on the 🖼 icon, that opens as a separate tab in the web browser, where the spectrum is displayed alongside its header.

The plotting interface is shown in Fig 19. The name of the spectrum is recalled as a global title of the page.
It contains two parts: the spectrum plot on the left and the header on the right. Both the absolute flux and normalized flux are displayed as a function of wavelength in Å in two distinct clickable tabs (the background of the selected is of the same colour as the spectrum on the plot). In the case of SEDs, there is only one tab, the background of which is also of the same colour as the spectrum on the plot.

The plots are interactive : the User may choose a logarithmic display for the ordinates (Change y scale), enter the wavelength range of the chart below the plot, or simply zoom with the mouse directly on the plot.
The plot can be reset to default boundaries at any time by clicking on the Reset zoom button.
It can also be enlarged (and reduced) by clicking on the ⛶ icon.
The displayed plot can also be saved as a .png file using the Save to PNG button.

From this display page, the spectrum can be either downloaded Download or added to the "MY SPECTRA" workspace Add to my spectra , with the buttons right above the header file display.

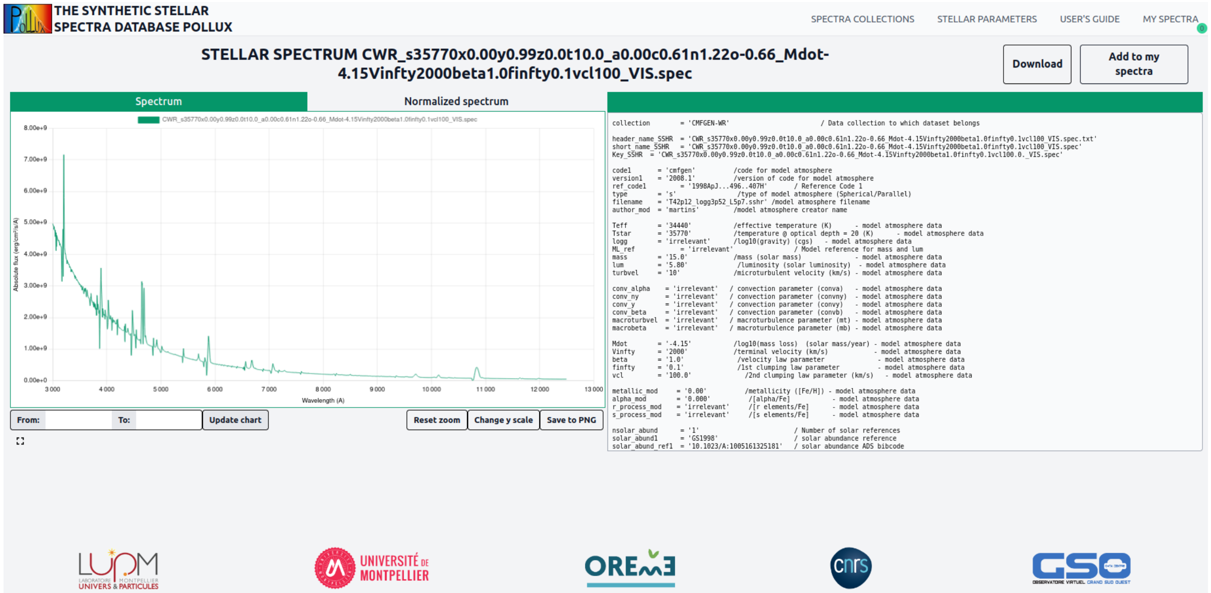


Figure 19: Example of spectrum and header display.

3. The third column of the query result allows the direct download of the spectrum in various formats. Clicking on the , a pop-up appears as in Fig. 20, where the pre-selected download format is Flat Table in zip format, and other formats can be also chosen (FITS , XML Table , XML Binary VoTable) before actually downloading.

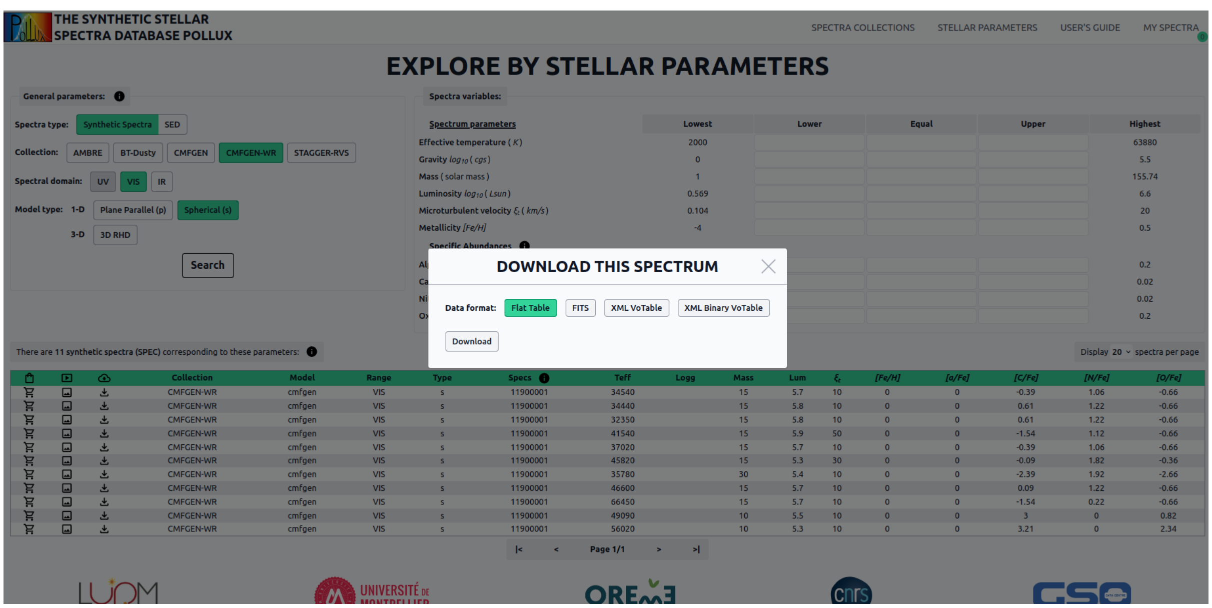


Figure 20: Direct download of a spectrum

In order to clearly acknowledge the producers of the data (HRSS or SEDs), a README.txt file (reproduced hereafter) is systematically added to the archive to be downloaded in which explicit names and papers according to collections to be cited along with the POLLUX database.

You will find here the synthetic stellar spectra you have selected and downloaded from the POLLUX database (pollux.oreme.org).
The spectra distributed in the POLLUX DB are to be acknowledged according to their producers:

CMFGEN-WR :	*F. Martins, private communication*
CMFGEN :	*F. Martins, for the POLLUX DB*
	Martins & Palacios, 2022, A&A 659, A63
	Martins & Palacios, 2021, A&A 645, A67
	Martins & Palacios, 2017, A&A 598, A56
AMBRE :	*de Laverny et al. 2012, A&A 544, A126*
RSG :	*E. Josselin, for the POLLUX DB*
STAGGER and STAGGER-RVS :	*Chiavassa et al. , 2018, A&A 611, A11*
	Magic et al., 2013, A&A 557, A26
	Chiavassa e al., 2009, A&A 506, 1351
BT-Dusty :	*F. Allard, for the POLLUX DB*

The database should be acknowledged with Palacios et al., 2010, A&A 516, A13.

You will find all relevant information concerning the data, the codes and the inputs used to generate them, as well as detailed curation information in the header file attached to each spectrum.

Thank you for using the service!

The POLLUX DB Team.

4.3.2 Spectrum Parameters

Columns 4 to 21 of the table present the data characteristics. It adapts to the selected General parameters and can differ from one collection to another. When the query concerns several collections, only the common data characteristics to all the selected collections are displayed.
In any case, columns 4 to 8 are always the following :

4. Collection Subset to which the spectrum belongs
5. Model Radiative transfer code used to compute the spectrum
6. Range Spectral Domain
7. Type **s**pherical, **p**lane-parallel or **3D RHD** model atmosphere
8. Specs Specifications of the synthetic spectrum as defined in Tab. 4.

The remaining columns will depend on the collections selected and can be

9. T_{eff} Effective temperature in K
10. $\log g$ Surface gravity in log
11. Mass Stellar mass in $M_\odot$ units - only relevant for **s**pherical models
12. Lum Logarithm of the stellar luminosity expressed in $L_\odot$ units - only relevant for **s**pherical models
13. ξ_t Micro-turbulent velocity in km.s^{-1}
14. [Fe/H] Metallicity with respect to solar
15. [C/H] Carbon abundance
16. [N/H] Nitrogen abundance
17. [O/H] Oxygen abundance
18. [α/H] α elements abundance
19. [*s*-elements/H] abundance of *s*-elements
20. [*r*-elements/H] abundance of *r*-elements

Clicking on the label of these columns will sort the data in the table in decreasing or increasing values of the selected parameter.

For the specific case of Wolf-Rayet spectra (CMFGEN-WR collection); the data characteristics of columns 9 to 18 are the following

9. T^* temperature at optical depth $\tau = 20$
10. Lum Logarithm of the stellar luminosity expressed in $L_\odot$ units
11. ξ_t Micro-turbulent velocity in km.s^{-1}
12. X hydrogen mass fraction
13. Y helium mass fraction
14. [Fe/H] Metallicity with respect to solar
15. X_C carbon mass fraction
16. X_O oxygen mass fraction
17. X_N nitrogen mass fraction

4.4 The "MY SPECTRA" workspace

Newly introduced in the present version of the database portal, the workspace is where data analysis and download is meant to be done. It is presented in Fig. 21.

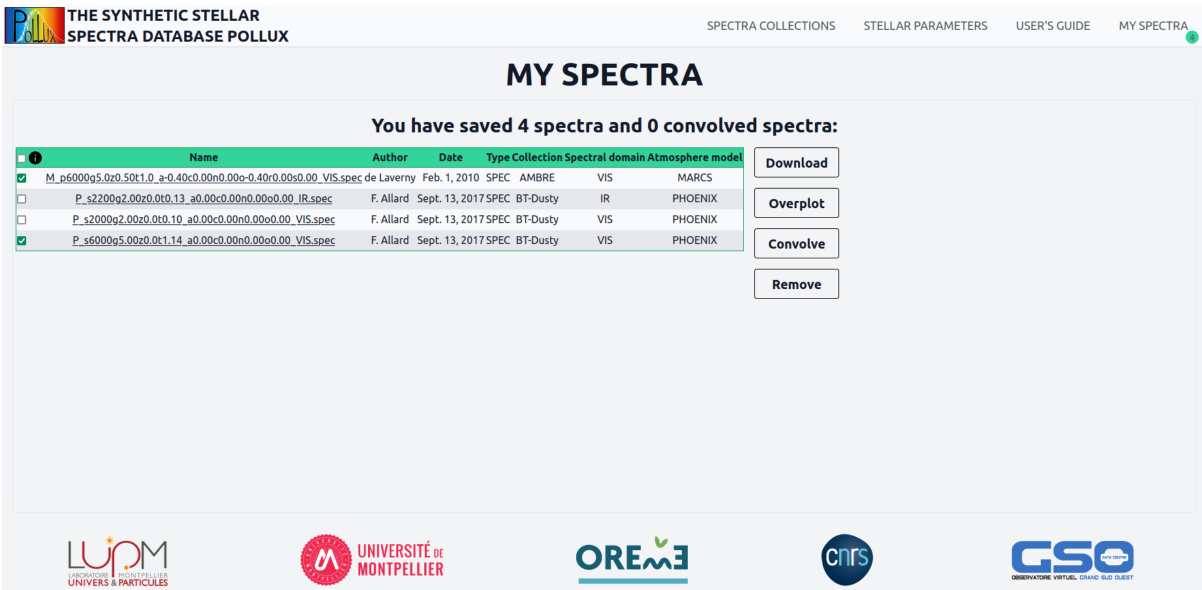


Figure 21: The MY SPECTRA workspace

The names of the spectra in the "MY SPECTRA" page can be clicked : this will open a new tab in the web browser containing the plot and the display of the spectrum.

Moreover, four functionalities are available from the workspace :

1. Download

   From the MY SPECTRA workspace, the selected spectra can be downloaded (default download format will be Flat table and FITS, XML and XML VoTable are also available for selection) with the same pop-up interface as from the result of query page described illustrated in Fig. 20.

2. Overplot

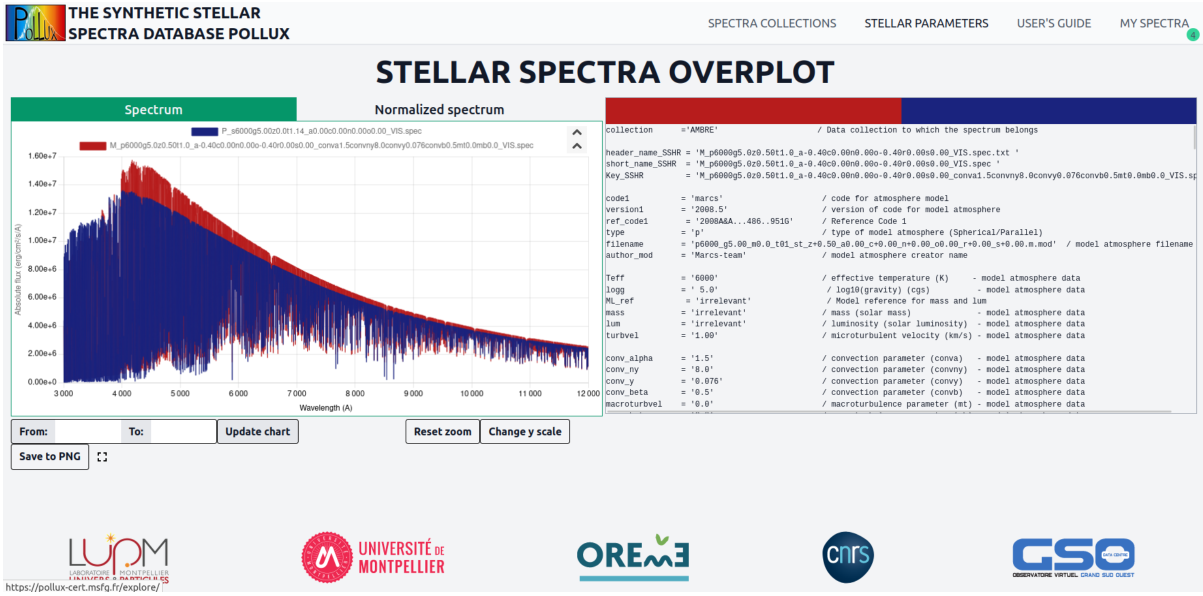


Figure 22: Overplot of two spectra from the MY SPECTRA workspace

The selected spectra in the workspace can be overplotted. The plot will appear in a new tab of the web browser. Each spectrum on the overplot is assigned a colour, and the different tabs on the right part of the window are coloured accordingly. The header of the corresponding spectrum is displayed when clicking on the corresponding colour tab. Per default, the displayed header is the one of the first spectrum as listed as a title of the plot.

The plot functionalities are as described before. There is an additional possibility of changing the order of the plotted spectra to improve clarity by clicking on the arrows on the right of the name of each spectrum. Clicking directly on the name of the spectrum in the title of the plot will moreover hide the selected spectrum. It will be shown again by clicking a second time on its name.

3. Convolve

The interface provided by clicking on this button, and shown in Fig. 23 allows the query of the SPECONVOL VO service based on a Fortran code that implements a number of convolution functions used to model the instrumental profile, the macroturbulence and the rotational broadening of spectral lines.

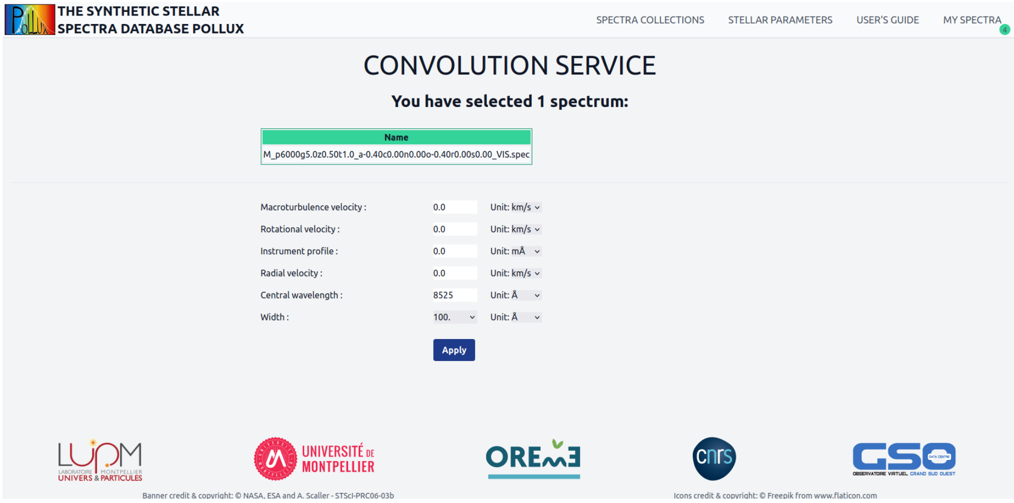


Figure 23: Interface to the SPECONVOL convolution service.

The user can choose to include one to four of the following convolution parameters:

- Macroturbulence velocity can be specified in km.s^{-1}. It is modelled by a radial tangential anisotropic profile as described in Gray (2005, pp 433), and describes the lines broadening due to convection;
- Rotational velocity of the star can be specified in km.s^{-1}. It is modelled by a ”rotation” profile as described in Gray (2005, pp 434-436), and describes the lines broadening due stellar rotation;
- The simulated signature of an instrumental profile can be specified in m$\AA$ (default unit) or in km.s^{-1}. It is modelled by a Gaussian profile and describes the line broadening due to the instrumental design.

The convolution parameters are applied to a spectral window centred at a chosen central wavelength that can be specified in units $\AA$, and of limited width to be chosen between 100 $\AA$ and 500 $\AA$.

The convolved portion of spectra can also be translated according to the a radial velocity that can be specified in units of km.s^{-1}.

These parameters are sent to the SPECONVOL service when clicking on the apply button and the user is redirected after a short time to the workspace page that now includes the initially selected spectra and the associated convolved portions.

A new name is given to the convolved spectrum, integrating the parameters of convolution as illustrated in Fig. 24

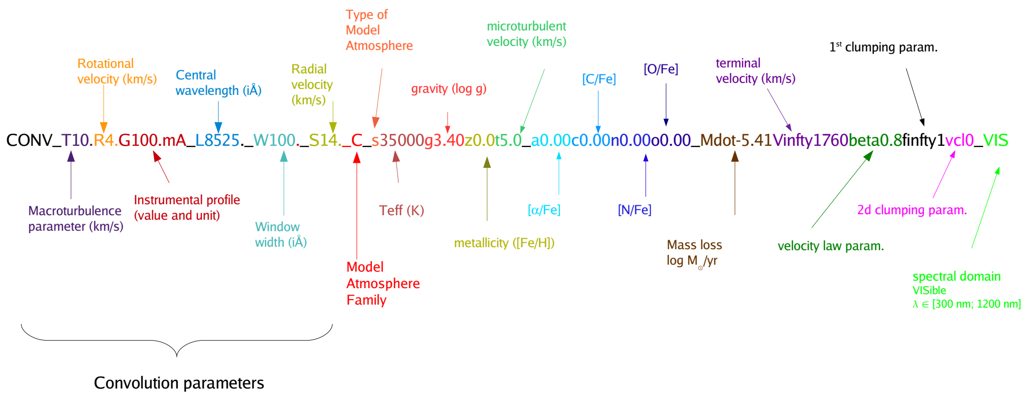


Figure 24: Example of nomenclature for a convolved portion of a spectrum using SPECONVOL.

The original spectrum and the convolved portion can be overplotted using the graphical tool within the interface as illustrated in Fig. 25.

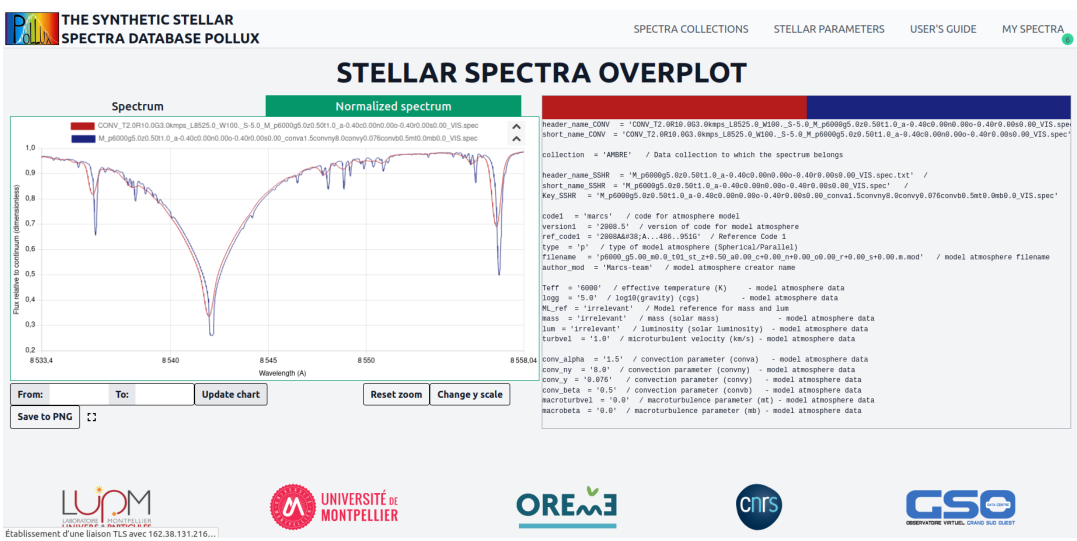


Figure 25: Rendering of overplotted spectrum and convolved portion.

4. Remove

This last button allows to remove spectra from the workspace.

5 FUTURE DEVELOPMENTS

5.1 ATLAS data to fill the gap of warm stellar spectra

The archive will be completed with corrected data sets derived from ATLAS model atmospheres at various metallicities.

5.2 Repository for the data produced within the POPSYCLE project

The project POPSYCLE (POPulation SYNthesis for CLusters and galaxiEs, `https://popsycle.univ-lyon1.fr/`) has been funded by the ANR (French Science Fund) for a duration of 4 years starting January 2020. It is lead by Pr. Ariane Lançon of Université de Strasbourg.
This project aims at contributing to the much needed improvement of Stellar Population Synthesis models (from the NUV to the NIR), with globular clusters and early type galaxies as primary validation targets. It includes the computation of a dedicated library of synthetic spectra computed with SYNSPEC48 based on ATLAS and Kurucz model atmospheres, that will account for the surface chemical composition variations observed and predicted by state-of-the-art stellar evolution models for the first time.
This library will be made publicly available through the POLLUX database by the end of the project (2024 – 2025).

5.3 Repository for the data produced within the Science Preparation of the PLATO Mission

PLATO is a M-class mission of ESA, a space telescope designed to discover exoplanets like the Earth orbiting bright solar-type stars, to be launched by December 2026. The mission will distribute light curves and science ready products such as the masses, radii and ages of the observed stars, as well as their fundamental parameters (effective temperature, surface gravity, metallicity...). To do so, a grid of stellar spectra has been computed using the MARCS radiative transfer code and the NLTE version of the spectral synthesis code TURBOSPECTRUM. The POLLUX team is considering, in agreement with the data producers and the PLATO consortium, to include a PLATO collection to the database, first with a restricted access only granted to the PLATO consortium members, and then opening it for all users.

5.4 Extension of the database to IR

Considering the new generation of spectrographs that are being built, a new effort to provide theoretical data in the IR domain should be done and we are working on this aspect in order to be able to provide the community with well described ans VO-compliant IR high resolution synthetic spectra.

5.5 (Re-)Introduction of SEDs

The introduction of spectral energy distributions (SED data) for warm and cool stars will be considered in the future.

5.6 (Re-)Introduction of RSG spectra in the optical domain

The optical counterparts of the IR RSG spectra should also be included in a forthcoming version.

6 CREDITS

The POLLUX database is described at length as of its third release, in a Palacios et al. (2010). When using POLLUX data for scientific publication, please quote :

Palacios A., Gebran M., Josselin E., Martins F., Plez B., Belmas M., Lèbre A., 2010, A&A 516, A13

and mention the following sentence:

This research was achieved using the POLLUX database (http://pollux.oreme.org/), operated at LUPM (Université de Montpellier - CNRS, France) with the support of the PNPS and INSU.

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