FADO v.1B patch 1.0

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ONLINE MANUAL

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Spectral population synthesis through genetic optimization under self-consistency boundary conditions

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Note: It is important to bear in mind that a distinctive characteristic of FADO is its ability to identify the star formation- and chemical enrichment history (SFH and CEH, respectively) that self-consistently reproduce the nebular characteristics (hydrogen Balmer-line luminosities and equivalent widths-EWs, nebular continuum incl. the Balmer and Paschen jump) of a galaxy. For this concept to work, the spectral indicators (e.g., Balmer-line luminosities and EWs) taken into account in the fit (in particular, in its full-consistency mode; FCmode) must be determinable from the input spectrum with sufficient accuracy (which implies that a spectrum to be modeled must have a sufficient S/N ratio and that it has been properly reduced). FADO (V.1B) incorporates various quality checks (e.g., automatic clipping of spurious spectral features, examination of the supplied error spectrum and auto-determined emission-line ratios) prior to fitting, however, it is the responsibility of the user to make sure that an input spectrum to FADO is of adequate quality.

Note that FADO is an evolving project with regular updates foreseen. For a detailed documentation and address questions and requests contact the jean@astro.up.pt

Description of file: FADOV1B_patch1.0.tar.gz

If you list the files after decompressing you should get:

SIZE [bytes]	FILES	Description
7234080	FADO	FADO binary (executable) OpenSuSE 13.2 64bit LINUX
6664	FADO.config	FADO configuration file for the fitting
7003036	FADO_MACOSX	FADO binary (executable) MAC OS X WARNING: not available in this version (see previous version of FADO) Not recommended!
66020	grfont.dat	FONTS for PGPLOT in binary
557436	grfont.txt	FONTS for PGPLOT
324993	.HeIfboundem.ascii	Auxiliary file for running FADO (Automatically created in case do not exist)
44222	.HeII_fbound.ascii	Auxiliary file for running FADO (Automatically created in case do not exist)
21286	.HIfbound_em.ascii	Auxiliary file for running FADO (Automatically created in case do not exist)
4096 • 129720 • 144024 • 186870	Input • spec1.txt • spec2.txt • spec3.txt	Directory with three SDSS-DR7 de-redshifted spectra • Starburst galaxy • Composite galaxy • Liner|Lier galaxy
4096	output	Empty directory for output files
2815	PLOT.config	FADO plotting configuration file
4096	plots	Empty directory for plots
4096 • 84274 • 10038	ReadMe • ReadMe • Read_F	ReadMe directory • ReadMe: file containing a general description • Read_F: file containing FADO v.1A short manual
12288 • 11124 • 179597	SSPs • Base.BC03.L • bc2003_hr_m*_chab_ssp_***.spec	Simple stellar population directory • Base file with SSP elements • Typical spectrum from a SSP
4096	tables	Empty directory for tables

1) Introductory notes

This document provides a concise overview of the main invocation options of the population spectral synthesis (PSS) code FADO (Gomes & Papaderos 2017, A&A, 603, A63). The tarball file **FADOV1B_patch1.0.tar.gz** contains, besides the FADOv1b_patch1.0_gcc4.8.5 (v.1B patch 1.0, hereafter referred to FADO only) binary, all necessary auxiliary files for executing FADO, along with three 1D spectra (in ascii format) from SDSS DR7 (de-redshifted and corrected for foreground Galactic extinction) and a library of simple stellar population (SSP) spectra from Bruzual & Charlot (2003, MNRAS, 344, 1000) for demonstration purposes.

2) FADO release version V.1B patch 1.0

OdieAuroraJM is the first version of FADO (referred to in the following as V.1B patch 1.0). In order to verify your version type:

```
$ ./FADO -version
```

3) Acknowledgements and Legal Stuff

Publications making use of FADO (or derivatives of it) and its subsequent releases must acknowledge the presentation article of the code by Gomes & Papaderos (2017, A&A, 603, A63).

This work was supported by Fundação para a Ciência e a Tecnologia (FCT) through national funds and by FEDER through COMPETE by the grants UID/FIS/04434/2013 & POCI-01-0145-FEDER-007672 and PTDC/FIS-AST/3214/2012 & FCOMP-01-0124-FEDER-029170. We acknowledge support by European Community Programme (FP7/2007-2013) under grant agreement No. PIRSES-GA-2013-612701 (SELGIFS). J.M.G. was supported by the fellowship SFRH/BPD/66958/2009 funded by FCT (Portugal) and POPH/FSE (EC) and by the fellowship CIAAUP-04/2016-BPD in the context of the FCT project UID/FIS/04434/2013 & POCI-01-0145-FEDER-007672. P.P. was supported by FCT through Investigador FCT contract IF/01220/2013/CP1191/CT0002. We thank Mayanna Gomes for the invaluable discussions related to the field of genetics and Leandro Cardoso for extensive tests of FADO.

By using FADO one implicitly agrees with the Copyright and Liability statements that should be viewed by executing:

```
$ ./FADO -license
```

FADO V.1B patch 1.0 is intended for education and research purposes. The output from FADO V.1B patch 1.0 uses PGPLOT version 5.2.2 and CFTSIO version 3.370 subroutines. Below we include the corresponding copyright notices that can also be viewed by executing:

$ ./FADO -thirdpartylicenses OR $ ./FADO -thirdparty

```
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*    Version 3.370                                                     *
************************************************************************
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```

4) Brief remarks and concise online manual:

To run FADO the user must have copied the editable files FADO.config and PLOT.config in the directory where the binary is stored ($FADO_home, or in a directory indicated by the "-c" option). FADO.config contains parameters controlling the fitting scheme and PLOT.config those defining the graphical output in encapsulated postscript (EPS) format (see [Note 7] and Appendix C for a detailed explanation).

The spectral fitting output from FADO is stored in four FITS files with the extension _1D, _EL, _ST and _DE (see Appendix B for details).

Various options (in any random order) can be passed to FADO (use the command "./FADO -help" or "./FADO -options" for further instructions). For a standalone run the essential parameters expected by FADO are five (5):

```
$ ./FADO -i par1 -b par2 -s par3 -r par4 -d par5
```

Primary parameters that SHOULD be provided by the user for optimal fits

OPTION	Brief Description
-i	spectrum to be modeled (e.g., "-i galaxy.fits"). Alternatively, a list of spectra can be provided with the -l option (see [Note 1])
-b	path to a directory containing the SSP base and the library of the SSPs to be used for the spectral modeling (e.g. "-b $FADO_home/SSPs/basefile"). An example of such a SSP base comes with the distribution tarball (the basefile is Base.BC03.L).
-r	resolution (mean FWHM across wavelength in [Å]) of the input spectrum (example: "-r 2.3" for a spectrum from SDSS DR7). We note that it is essential to provide the spectrograph's resolution in order to optimize the fit solution due to clipping and continuum/error estimation. After FADO V.1B, the -r option DOES convolve the library SSP spectra with that of the observed spectrum. We advise that this should be done using a line spread function, but most of the observations lack this information from the spectrograph.
-s	the first two parameters indicate the spectral range used in the modeling and for which the synthetic best-fitting model is exported. The third parameter gives the wavelength stepsize at which the fit is computed and exported into FITS format (file extension: _1D) (example: "-s lambdamin lambdamax lambdastep"; see [Note 2]).
-d	distance to the galaxy in Mpc (example: "-d 20"). If omitted, FADO assumes a distance of 10 Mpc for computing distance-dependent quantities (e.g., stellar masses, Lyman continuum photon rates).

Secondary (optional) parameters - WARNING: two options have changed after FADO v.1B release

OPTION	Brief Description
-c	directory containing the configuration file FADO.config. If omitted, FADO assumes that it is available at home directory $FADO_home (example: "-c $FADO_home/ConfigFiles/FADO.config"). If not present in $FADO_home, FADO.config is automatically generated with default parameters (see Appendix A) upon first execution of FADO.
-e	Optional feature allowing the user to choose the extinction law. FADO V.1B now integrates several attenuation laws: ALLR: Stands for Allen (1976); CALR: Stands for Calzetti (2001, PASP, 113, 1449C); ALE: Stands for Calzetti (2001, PASP, 113, 1449C) extended to the FUV; CCMR: Stands for Cardelli, Clayton & Mathis (1989, ApJ, 345, 245C); FLMC: Stands for Fitzpatrick (1986) for the LMC; GOR1: Stands for Gordon et al. 2003 - SMC Bar; GOR2: Stands for Gordon et al. 2003 - LMC SuperShell; GOR3: Stands for Gordon et al. 2003 - LMC Average; PREV: Stands for Prevot et al. (1984) and Bouchet et al. (1985) for the SMC; SFMW: Stands for Seaton (1979) plus Fitzpatrick (1986) for the MW. If no option is given, CALE is used as default. Please be reminded that FADO does not correct spectra for Galactic foreground extinction. In case no correction for Galactic foreground extinction has been applied prior to running FADO, the computed visual extinction A_V, both in the stellar and nebular component, includes the Galactic contribution to the reddening.
-g	assumed physical conditions for the nebular component: if set to 0, a fixed electron temperature T_e and density n_e taken from the FADO.config file is going to be adopted. If this option is set to 1 (or not supplied), T_e and n_e are determined on-the-fly by FADO, whenever possible and meaningful, from an emission-line spectrum (see [Note 3]).

-l	list of spectra in a directory to be processed sequentially (e.g., "-l $FADO_home/InputSpectra/spectra.list"). This is equivalent to the -i option, and preferable for batch mode execution, since this reduces memory allocation and skips the need to repeatedly read and pre-process library SSPs. Obviously, the -i and -l option cannot be used simultaneously (this is prevented by FADO). The list of spectra can also be provided in a two-column format, with the first column listing the spectra and the second one containing the distance in Mpc. Please note that if the "-d" option is supplied together with the "-l" option, then all spectra in the list will be modeled assuming the same distance, i.e. the value provided by the "-d" option.
-o	directory where the model output should be stored (example: "-o $FADO_home/Results"). If omitted, the output from FADO will be exported in the directory where the input spectra are stored.
-p	as -o but for the graphical output. If omitted, the EPS output will be stored either in the directory indicated by the -o option or in the directory where the input spectra are located.
-t	table options to be used together with the -l command (see above) to redirect the output tables to a given directory. If omitted, the table output from FADO will be exported in the directory where the input spectra are stored. The tables created are always two with the following prefix: SampleEmissionEL_"$suffix_table".table and SampleStatistics_"$suffix_table".table. The $suffix_table can be chosen by invoking the -t option with both the directory and suffix; in case the latter is not provided then $suffix_table=FADO is used by default (e.g., for example, SampleEmissionEL_FADO.table). These ascii tables contain relevant output also stored in FITS format for individual spectra; since each row corresponds to a different spectrum, the -t option facilitates analysis of big datasets.
-u	flux units in erg/(s*cm**2*Å) of the input spectrum. This parameter is necessary only in the exceptional case when the flux is not coming in erg/(s*cm**2*Å), for example when the spectrum is passed in a 2-column ascii format, with the flux in the second column having being previously normalized to, e.g., 1.e-17 erg/(s*cm**2*Å).
-v	determination of the redshift of the source. Two options associated with three parameters can be given: a) "-v min_recessional_velocity max_recessional_velocity delta_velocity". This option will activate an automatic search for the recessional velocity between min/max_recessional_velocity (we recommend a velocity margin of **+/- 400 km/s** for absorption-line spectra, whereas for emission-line spectra a larger range of +/-10^3 km/s is possible, on an experimental basis at this stage) (see [Note 4]).
-pdir	directory containing the configuration file PLOT.config. If omitted, FADO assumes that it is available at the home directory $FADO_home. If not present in $FADO_home, both configuration files are automatically generated with default parameters (see Appendix A) upon first execution of FADO.
-verbose	verbosity level (00 to 10). Use ./FADO -verbosity for more information.

5) NOTES

[1] A flux- and wavelength-calibrated spectrum can be provided to FADO both as an ascii or in standard FITS format. In the case of an ascii table, the first and second column must contain the wavelength (Å) and the flux (erg/s*cm**2). A third column will be interpreted as the error spectrum. Likewise, FADO assumes that a second array in a FITS data file holds the error spectrum. Whenever the latter is not provided by the user, it is automatically estimated by FADO. Please note that intervals in which the error spectrum is not given or has dubious (e.g., very high, zero or negative) values are automatically substituted by the error spectrum being internally computed by FADO. FADO does not require an input spectrum to be de-redshifted, however, we recommend its application to de-redshifted spectra. Rebinning a spectrum

to a constant wavelength step is not needed (in fact, we recommend to avoid rebinning of spectra prior to fitting, since this is done by FADO using a flux-conserving routine). However, it is expected that the input spectrum has been corrected for Galactic foreground extinction (not to be confused with intrinsic galactic extinction) using, for instance, maps of dust IR emission and the CMBR foreground for estimating the reddening (e.g., Schlegel, D., Finkbeiner, D., & Davis, M., ApJ, 1998, 500, 525).

[2] The three parameters passed to FADO with the option -s indicate, respectively, the minimum and maximum wavelength in Å (lambdamin and lambdamax, respectively) and wavelength step (lambdastep) of the best-fitting synthetic model. The latter is stored in the FITS file with the extension _1D and, depending on the fitting scheme used by FADO, it contains separately the contribution of the stellar and nebular continuum component (IsNEBcOn=1, see appendix A).

We note that lambdamin, lambdamax and lambdastep must not necessarily match those of the input spectrum. For example, the best-fitting model to a spectrum covering the spectral range between 3000 and 9000 Å in steps of 2 Å can be computed for the spectral range between 2000 and 8000 in steps of 1 Å. On the other hand, the choice of lambdastep must be meaningful. For example, when modeling a spectrum with a spectral resolution of ~2 Å, it is generally of little benefit to export the best-fitting SED with an lambdastep of 0.2 Å. Conversely, choosing an unreasonably high lambdastep (say, 20 Å for an input spectrum with a 2 Å FWHM) will erase a substantial part of the spectral information encoded and almost certainly impact the fit. This is because several parts in the fitting procedure (e.g., automatic flagging of emission lines, on-the-fly determination of the electron density from the [SII]6717,6731 doublet, determination of Balmer-line fluxes and equivalent widths) are executed at the spectral resolution defined by the -s (lambdastep) and -r (Resolution) parameters.

As a rule of thumb, we recommend for lambdastep a value that is by a factor ~2.35 smaller than the mean FWHM resolution of the spectrum (for example, an lambdastep of 1.0 Å for a SDSS DR7 spectrum with a mean resolution of 2.3 Å FWHM would be a good choice).

[3] As described in the FADO presentation article (Gomes & Papaderos 2017), whenever possible FADO computes on-the-fly n_e and T_e. In case standard conditions are to be assumed, the option "-g 0" should be used. Since this conflicts with the self-consistency principles of FADO it is not recommended to use this option. Obviously, in the case of very noisy spectra (S/N <~ 10) these two quantities are highly uncertain. If the electron density n_e is uncertain or not correctly determined (which will lead FADO to adopt the n_e indicated in the FADO.config) then it is generally doubtful that the electron temperature T_e is correct (due to the weakness of the [OIII] 4363 line). A critical inspection of the fit is recommendable in this case.

[4] The current version of FADO (V.1B) permits automatic determination of the recession velocity of emission-line galaxy spectra of moderate-to-good S/N within a margin well beyond 1000 km/s with the option "-v -1000 1000 10". However, we recommend the usage of the redshift option between +/-400 km/s, i.e. "-v -400 400 10" in already de-redshifted spectra for the FADO V.1A version.

[5] FADO automatically determines and rejects emission-lines prior to and during the fitting with a clipping technique.

[6] We recommend to not modify the parameters from the FADO (V.1B) distribution in the configuration file, specially those in the <FADO FITTING> section. For instance, Self_Con should be always be set = 2 (see explanation in the main paper and Appendix A).

[7] It should be noted that the color coding in the graphical output (EPS) gives information on whether certain quantities could be reliably determined: whenever possible, FADO determines the nebular physical conditions (e.g., T_e, n_e, [NII]/Ha, [OIII]/Hb and EW(Halpha)) and, if successful, it displays the results in red, otherwise in light blue. Quantities related to the stellar population properties derived by FADO are displayed in black.