GALA cookbook

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1.   Introduction

GALA (Mucciarelli et al. 2013) is a code written in standard Fortran 77 and aimed at finding the best atmospheric parameters and the abundance of individual elements by using the equivalent widths (EWs) of metallic lines, providing graphical and statistical tools to evaluate the goodness of the solution. The derivation of the abundances is performed by using a modified version of the WIDTH9 code[1] (originally developed by R. L. Kurucz) in its Linux version (Sbordone et al. 2004). In the current release, GALA can manage the classical grid of ATLAS9 models computed by Castelli & Kurucz (2004), the grid of new ATLAS9 models computed for the APOGEE survey (Meszaros et al. 2012) and the MARCS models with the standard composition (Gustafsson et al. 2008). When the ATLAS9 models are used, new model atmospheres are calculated starting from an existing guess model and according to the pre-tabulated Opacity Distribution Functions (ODF) and Rosseland opacity tables. When MARCS are used, each new model is obtained by interpolating within the MARCS grid.

2.   Installation

Once you have downloaded the archive file `gala.tar.gz` from the website

`www.cosmic-lab.eu/Cosmic-Lab/Products.html`,

type the commands

```
gunzip gala.tar.gz
tar -xvf gala.tar
```

These commands unpack the archive file creating a directory named `GALA/`. Within this directory there are three subdirectories (`src/`, `bin/` and `tutorial/`) together with some information

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[1] http://wwwuser.oat.ts.astro.it/castelli/sources/WIDTH.html.

files. The directory `src/` includes all the source files and the `Makefile` needed to install GALA. The directory `bin/` includes the executables created after the installation. In the directory `tutorial/` there are some examples of the input files for GALA as reference.

(1) <u>Install ATLAS9</u>

Before starting the installation of GALA, you need to install in your machine the ATLAS9 code if you plan to use these models (obviously, if you plan to use only MARCS models you can avoid to install ATLAS9). GALA includes a dynamical call to the last version of this code, available on the website of F. Castelli[2]. Download the source code `atlas9mem.for` with the command

`wget -r -nd http://wwwuser.oat.ts.astro.it/castelli/sources/atlas9/atlas9mem.for`

and compile it

`ifort -double-size 64 -save -o atlas9mem.exe atlas9mem.for`

Note that GALA assumes that you have this code installed and that the executable is named `atlas9mem.exe`. Please do not compile ATLAS9 with different names.

(2) <u>Set the Makefile</u>

Firstly, you need to properly update the `Makefile`. GALA can be compiled with the Intel Fortran Compiler, that you can download from the Intel website[3], after the registration. Also, the graphical output files are created by the program `galaplot` using the SuperMongo[4] (SM) libraries (namely `libplotsub.a`, `libdevices.a` and `libutils.a`, compiled in single precision) and the X11 libraries. Set in the first lines of the `Makefile` the path of your Intel Fortran Compiler and that of the directory where the SM libraries are located.

(3) <u>Set some useful paths</u>

Now, you need to properly set in the `GALA/src/Paths.f` file the paths of some directories used by the code:
(1) 'exe' = it is the path where the executables of GALA are located (the subdirectory `bin/`);
(2) 'at9exe' = it is the path of the directory where the executable `atlas9mem.exe` is located;
(3) 'at9fc' = it is the path where the ATLAS9 models by Castelli & Kurucz (2004) are saved, see

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[2]http://wwwuser.oat.ts.astro.it/castelli/sources/atlas9codes.html

[3]http://software.intel.com/en-us/non-commercial-software-development

[4]http://www.astro.princeton.edu/∼rhl/sm/

Section.7;

(4) 'at9apo' = it is the path where the ATLAS9 models by Meszaros et al. (2012) are saved, see Section.7;

(5) 'marcs' = it is the path where the MARCS models with the standard composition by Gustafsson et al. (2008) are saved, see Section.7.

The directories of the ATLAS9 models need a precise structure. In each directory you need to create three subdirectories, namely `ODF/`, `MODELS/` and `MODELS-new/`, the first including the ODFs and the Rosseland opacity tables, the second including the grid of model atmospheres used as guess models, while the third is the directory where the new models created during the run of GALA will be saved. The directory for the MARCS models does not need a specific substructure. Examples of these subdirectories, as well as more details about the use of the different model grids, are discussed in Sect. 7.

Note that you do not need to have necessarily all these models to use GALA. If you plan to use only a given kind of models, you can delete or leave blank the paths of the other models in the `Paths.f` file (but in this case do not try to call them when you run GALA).

(4) <u>And now...install GALA!</u>

To install GALA, type the command

```
make all
```

and the executables will be saved in the subdirectory `/bin`.

Finally, put the path of the subdirectory `bin/` in your login file according to the shell environment of your machine (for instance in the configuration file .bashrc or .tcshrc). The directory `/tutorial` includes examples for the three input files. You can check the installation of GALA by using these files and simply type `gala`.

Note that GALA is dimensioned to manage up to 1200 spectral lines for each star (parameter INL in the source file `Declare.f`). If a given star has more than this number of measured transitions, GALA skips this star providing a warning message. For our experience this value is reasonable but if you think the this limit is too low for your stars, you can increase the parameter INL and recompile the code (note that a uselessly high value for INL will lead to a waste of computer memory).

3. Installation problems

We list some common installation problems (typically related to the combination Fortran compiler/system architecture) and their possible solutions.

- The SM libraries compiled in double precision can give problems during the compilation or

(when the compilation well works) `galaplot` creates corrupted or badly drawn postscript files. We recommend to use for `galaplot` SM libraries compiled in single precision. Because it is usual to compile SM in double precision, we suggest to perform two distinct installations of SM, in order to save wherever you want the libraries compiled in single precision. The instructions to perform the installation of SM are explained in the `sm.install` file in the directory of the SM source code.

- A warning message appears during the compilation of `galaplot` like

```
ld:  warning in /Users/alessio/MAGAZZINO/SMONGO-lib-ELE/libplotsub.a, file is
not of required architecture
```

In this case, you can try to compile `galaplot` telling the compiler to generate the code for a specific architecture. You need only to add the option '-m32' (if your machine is a 32 architecture) or '-m64' (if your machine is a 64 architecture) in the `Makefile`

```
$(FORTRAN) -m32 -traceback - galaplot galaplot.f mplot1.f -lX11 -L$(SMLIB)
-lplotsub -ldevices -lutils.
```

- The SM commands under Fortran are unrecognized, with warning messages like

```
Undefined symbols:  "_sm_limits_", referenced from:  _mplot_ in ifortLFD1nn.o
```

This happens because some incompatibilities between the different names of the SM commands as defined by Fortran and C compilers can occur. The users with experiences with other tools devoted to spectroscopic analysis (as MOOG and DAOSPEC) have already dealt with these problems. We refer the reader to the Chapter 4 of the *DAOSPEC Cookbook*[5] as useful documentation to solve some of these problems.
With the last versions of the Intel Fortran Compiler, the SM commands have an extra '_' as suffix (not needed if you compile `galaplot` with G77 Fortran Compiler for instance). The source file `mplot1.f` calls the SM commands as *sm_limits_* and so on. Note that we provide a modified version of this file (named `mplot2.f`) where the SM commands are called with their standard names (i.e. *sm_limits*); you can try to compile `galaplot` with this source file, if the error messages shown above appear.

- If you cannot compile `galaplot` with the Intel Fortran Compiler because of incompatibilities between the SM libraries and the Fortran commands as called in the source code, you have two alternative options: *(1)* try to compile only `galaplot` with another Fortran compiler (as

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[5]http://www.bo.astro.it/∼pancino/docs/daospec.pdf

G77 for instance), substituting the file `mplot1.f` with `mplot2.f`; *(2)* if you cannot compile `galaplot` with other compilers, you can perform the installation of GALA without `galaplot`. In this case, you can easily disable the graphical option by commenting in the file `gala.f` the line

```
call system('galaplot')
```

and then compile the code with the command `make gala`.

4. Executable files

The executable files that will be created in the subdirectory `bin/` are:

1. `gala` — the executable file to run GALA;

2. `galaplot` — this program produces the graphical output for each analysed star;

3. `interpol_marcstoatlas` — this is a modified version of the code to interpolate the MARCS model atmospheres developed by T. Masseron and available in its original version at the website http://marcs.astro.uu.se/software.php. The current version writes the output MARCS model in the ATLAS9 standard format;

4. `marcstoatlas` — this routine reads an usual MARCS model atmosphere converting it in the ATLAS9 standard format. This routine is a modification of the program (developed by B. Edvardsson) available in the Uppsala website (http://marcs.astro.uu.se/software.php) and it can be used independently by GALA with the command-line instruction

```
cat < model-name > / marcstoatlas
```

(where < model-name > is the input MARCS model), storing in the Fortran unit 88 the ATLAS9-like output model;

5. `width9_gala` — this is a modified version of the WIDTH9 code available on the website of F. Castelli [6]. The main differences are the formats of the input and output files. Some control cards of WIDTH9 (see Castelli 1988) have been disabled because not used by GALA;

6. `extract_kur` — this program reads the classical linelists of Kurucz/Castelli [7] stored in a file named `master_linelist.tmp` and a file (named `input.dat`) including your linelist (in the

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[6] http://wwwuser.oat.ts.astro.it/castelli/sources/WIDTH.html

[7] http://wwwuser.oat.ts.astro.it/castelli/linelists.html

first column the wavelength in Å and in the second column the code of the element in the Kurucz formalism: i.e. 26.00 for FeI and 26.01 for FeII). The code matches the two files and writes in the output file (`output.dat`) the information needed to the GALA input.

7. `write_autofl` — this program writes the basic structure of the input file `autofl.param` (described in Section 5.1), with the proper name of each keyword.

5.   Input files

- `autofl.param` — it includes the main configuration parameters used by GALA to perform the analysis (described in Section 5.1);

- `list_star` — it is the list of the stars to analyse and their guess atmospheric parameters (described in Section 5.2);

- a file (one for each star listed in `list_star`) with extension `.in`, including the list of the measured lines, their EWs and their atomic parameters (described in Section 5.3).

5.1.   Layout of `autofl.param`

The input file `autofl.param` includes two groups of keywords, namely the basic parameters and the subordinate parameters. The command `write_autofl` writes the basic structure of the file (with some parameters already filled by default values); note that the order of the keywords (as well as the presence or not of the header lines) does not really matter. A template of this file is available in the subdirectory `tutorial/`.

(1) Basic parameters: these are the parameters that you need to set in order to perform the analysis:

- **model** specifies the kind of model atmospheres; the accepted values are
  -*atlas9* for the ATLAS9 model atmospheres available in the website by F. Castelli;
  -*apogee_cm150* APOGEE-ATLAS9 grid with [C/Fe]=–1.50;
  -*apogee_cm125* APOGEE-ATLAS9 grid with [C/Fe]=–1.25;
  -*apogee_cm100* APOGEE-ATLAS9 grid with [C/Fe]=–1.00;
  -*apogee_cm075* APOGEE-ATLAS9 grid with [C/Fe]=–0.75;
  -*apogee_cm050* APOGEE-ATLAS9 grid with [C/Fe]=–0.50;
  -*apogee_cm025* APOGEE-ATLAS9 grid with [C/Fe]=–0.25;
  -*apogee_cp000* APOGEE-ATLAS9 grid with [C/Fe]=+0.00;
  -*apogee_cp025* APOGEE-ATLAS9 grid with [C/Fe]=+0.25;
  -*apogee_cp050* APOGEE-ATLAS9 grid with [C/Fe]=+0.50;

```
# BASIC PARAMETERS
model       atlas9
guess       0
refine      0
uncer       0
qiron       26.00
epot        0
grc         0
vtc         0
metal       0
stepgr      0.1
stepteff    50
stepvt      0.1
ewmin       -5.5
ewmax       -2.5
error       10
iter        10
# SUBORDINATE PARAMETERS
rj          1
smax        3
minnfe      10
eplever     1.5
maxsig      1.0
minl        3
errfit      1
paropt      0
interz      0
kuriter     5
plot        1
verbose     1
```

-*apogee_cp075* APOGEE-ATLAS9 grid with [C/Fe]=+0.75;
-*apogee_cp100* APOGEE-ATLAS9 grid with [C/Fe]=+1.00;
-*marcs* for the MARCS model atmospheres with the standard chemical composition.

We refer to Section 7 to detail about the download of these models and the way to manage them in order to use correctly GALA. Alternatively, you can specify the name of a given model (in ATLAS9 format) [8] located in the working directory. If the specified model is found in the current directory, all the optimization options (together with the guess and refinement working-blocks) are switched off and only the analysis working-block is executed (with fixed parameters). Otherwise, if the specified model does not exist in the directory, GALA stops the procedure and exits with a warning message.

- **guess** enables the guess working-block, before the analysis working-block. The parameter is the number of iterations performed during this working-block. Guess= 0 (or negative values) disables the execution of this working-block. If you decide to use this option, we suggest to adopt at least 3 iterations for the guess working-block.

- **refine** enables the refinement working-block, after the analysis working-block. The parameter

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[8]If you wish to use a model atmosphere calculated with the ATLAS12 code (Castelli 2005a), you need to erase the 22 lines corresponding to the 'ABUNDANCE TABLE' control cards. Also, to use a specific MARCS model, you have to put it in ATLAS9 format with the program `marcstoatlas`.

accepts the values 0 (disabling the working-block) and 1 (enabling the working-block).

- **uncer** enables the calculation of the uncertainties in the derived chemical abundances due to the atmospheric parameters. The accepted values are

  0 : no uncertainties calculation is performed;

  1 : the uncertainties are calculated according to the prescriptions by Cayrel et al. (2004), only if T_{eff} has been optimized spectroscopically;

  2 : together with the uncertainties estimated with the previous method, also the uncertainties due to the atmospheric parameters following the classical method are calculated, varying each time one parameter only (keeping the others fixed) and without taking into account the covariance terms.

- **qiron** indicates the code of the element (with its ionization stage) whose lines are used to perform the optimization. The formalism is the same used in the Kurucz codes (i.e. 26.00 for Fe I and 26.01 for Fe II). In principle, GALA accepts all the elements but obviously only a few elements (i.e. Ti or Ni) have a sufficient number of available lines to perform a reliable spectroscopic optimization.

- **epot** enables the spectroscopic optimization of the temperature. The accepted values are

  0 : the temperature is not optimized and rather fixed to the input value;

  1 : the temperature is found by erasing any trend in the A(El)[9]—χ_{ex} plane (where χ_{ex} is the excitation potential in eV).

- **grc** enables the spectroscopic optimization of the gravity.

  0 : the gravity is fixed to the input value;

  1 : gravity is optimized in order to obtain the same abundance from neutral and single ionized iron lines;

  2 : if this option is chosen, GALA reads in `list_star` the term $\epsilon = \log(4GM\pi\sigma/L)$ and for each iteration log g is computed as log g=ϵ+4·T_{eff} (see Section 5.2);

  3 : the gravity is computed with a second degree relation logg= A+B·T_{eff}+C·T_{eff}^2. In this case the coefficients A, B and C are provided in the `list_star` file (see Section 5.2).

- **vtc** enables the optimization of the microturbulent velocity.

  0 : the velocity is fixed to the input value;

  1 : the microturbulent velocity is found by erasing any trend in the A(El)—EWR plane, where EWR is defined as $\log(EW/\lambda)$, where EW and λ are expressed in the same units.

- **metal** enables the optimization of the overall metallicity of the model atmosphere, that is chosen in order to reproduce the average abundance derived from lines of the element specified by the parameter `qiron` (within the metallicity step of the employed models grid).

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[9]A(El) indicates for a given element El the number abundance as calculated by WIDTH9.

- **stepgr** the step used to investigate log g in the analysis and refinement working-blocks;

- **stepteff** the step used to investigate T_{eff} in the analysis and refinement working-blocks;

- **stepvt** the step used to investigate v_{turb} in the analysis and refinement working-blocks;

- **ewmin, ewmax** these are the minimum and maximum value for EWR. All lines outside the EWR range defined by these parameters are excluded from the analysis. If you do not know a priori the optimal EWR range, a first run of GALA with a wide range including all lines is recommended (with EWR ranging from `ewmin`= -10 to `ewmax`= 0), followed by a more informed second run, with EWR limits deducted from visual inspection of the graphical outputs.

- **error** the maximum error in percentage in EW, in the case in which the error for each line is provided in the linelist file. All the lines with error larger than this threshold are excluded from the analysis.

- **iter** the maximum number of allowed iterations. This parameter avoids the risk of infinite loops. A reasonable value is 10 (if the input parameters are not so far from the real solution), but you should adapt this value to her/his particular needs.

(2) Subordinate parameters: these parameters specify some finer details of the analysis; we suggest to use the default values for these parameters, unless you have specific needs

- **rj** specifies whether the line-rejection uses the mean (`rj`=0) or the median value (default `rj`= 1).

- **smax** is the number of σ used in the line-rejection process (default `smax`= 3).

- **minnfe** corresponds to the minimum number of surviving lines that allows to perform the optimization. In principle, the spectroscopic optimization of the atmospheric parameters is a statistical method which requires a large (at least 40-50) set of lines. Optimizations derived with a low number of lines are affected by fluctuations due to the small number statistics and the lines distribution in the A(El)—χ_{ex} and A(El)—EWR planes (but these uncertainties are taken into account in the calculation of the errors through the Jackknife bootstrap technique). You should be careful that a very low number of lines (typically ten or less) would provide very dangerous results (default `minnfe`= 10).

- **eplever** the spectroscopic derivation of T_{eff} needs a large range of χ_{ex} covered by the used lines, in our opinion at least 1.5–2 eV. For smaller range, the optimization of T_{eff} can be unreliable. This keyword specifies the minimum χ_{ex} range (in eV) allowed to perform the optimization of T_{eff} (if requested). If the range of χ_{ex} (calculated considering only the lines

surviving line-rejection) is smaller than `eplever`, then the optimization of T_{eff} is swichted off; eventually, if the other parameters are to be optimized, their optmization continues (default `eplever`= 1.5).

- **maxsig** is the maximum dispersion by the mean or median for the element chosen with `qiron` allowed to run GALA. When the dispersion exceeds this value, all the optimizations are disabled and the analysis is performed with the input atmospheric parameters specified in the `list_star` file (default `maxsig`= 1.0).

- **minl** corresponds to the minimum number of lines to perform the process of line-rejection. If the number of lines is less than the value of `minl` ($N_{lines} \leq$ minl), the lines are rejected only on the basis of uncertainty in EWs (σ_{EW}) and of the pair of values `ewmin`–`ewmax` (default `minl`= 3).

- **errfit** specifies the kind of linear fit performed on the A(El)—χ_{ex} and A(El)—EWR planes.
  0 : the linear fits are computed without considering the uncertainties in x and/or y;
  1 : the linear fits are computed by taking into account the uncertainties in A(El);
  2 : the linear fit in A(El)—χ_{ex} is computed including the uncertainties in A(El) and that in A(El)—EWR including the uncertainties both in EWR and A(El), following the method implemented by Press et al. (1992).

  The use of the uncertainties in the slopes computation is recommended, but only if you have reliable errors in EWs, able to provide a realistic ranking among the used lines. If you do not trust your EW uncertainties, use `errfit`= 0. Note that if `errfit`= 1 or 2 but at least one of the input lines has σ_{EW}= 0.0, the inclusion of the errors in the slope calculation is disabled (default `errfit`= 1).

- **paropt** specifies the kind of optimization parameter used for T_{eff} and v_t:
  0 : optimizes these parameters by using the slopes (default);
  1 : by using the Spearman ranking coefficient.

- **interz** enables the interpolation to the zero value of the optimized parameters (`interz`= 1). This option is included to provide visually nicer results if one wants to plot temperatures and gravities in a T_{eff}—logg diagram. It interpolates the slope in the A(El)–χ_{ex} and the A(El)I-A(El)II to zero, and determines the corresponding T_{eff} and logg, thus avoiding the grid effect in the results. If this interpolation is switched off, all results will be in steps specified by the `stepgr`, `stepteff`, and `stepvt` parameters, while if the interpolation is switched on, they will be distributed more continuously. Note, however, that all uncertainties will still be computed on the best slopes, not on the interpolated zero slopes (default `interz`= 0) .

- **kuriter** specifies the number of blocks of 15 iterations each used by ATLAS9 to calculate a new model atmosphere (default `kuriter`= 5). This option is ignored if the keyword `model` is referred to MARCS models.

- **plot** enables the graphic output in postscript format
  0 : does not produce a plot;
  1 : saves the plot of the results in a postscript file (default option).

- **verbose** specifies the verbosity level on the terminal
  0: no message at all. It advises only when GALA ends the analysis;
  1: the sequence of the analysed stars is shown, without additional information;
  2: this is like `verbose=` 1 but also specifies the main steps performed by GALA (without additional information about them);
  3: this is the default verbosity level. It is like `verbose=` 2 but also displays information about the line rejection, the derived abundances and concerning the Guess Working-Block.

5.2.   Starlist file

The file `list_star` includes the sequence of the stars that you plan to analyse, together with the input atmospheric parameters. The structure of the file depends basically by the kind of the adopted optimization for the surface gravity (as specified by the basic parameter 'grc' in the file `autofl.param`).

- if you adopted grc= 0 or 1, each line of the file will be as follows:

```
ngc1806_25  4000   0.7  -0.5   2.0   0.0    0   0   0
ngc1806_27  4200   1.2  -0.5   2.0   0.0    0   0   0
ngc1806_29  4100   1.0  -0.5   2.0   0.0    0   0   0
ngc1806_30  4400   1.5  -0.5   2.0   0.0    0   0   0
ngc1806_32  4100   1.0  -0.5   2.0   0.0    0   0   0
ngc1806_40  4100   0.8  -0.5   2.0   0.0    0   0   0
```

Fig. 1.— Example of the `list_star` file when the option grc=0 or 1 is selected.

1. the first column contains the root name of the input files, without the extension `.in`;

2. the four following columns contain the guess atmospheric parameters in the following order: T_{eff}, log g, [M/H] and v_t. Note that if you provide a wrong value of [M/H] (not available in the chosen grid of models), GALA changes it and assumes the closest metallicity;

3. the sixth column contains the value of the α-enhancement adopted in the computation of the ATLAS9 models. Also in this case, if you provide a value of [α/Fe] not available among the models, the closest value is used. If you use MARCS models GALA neglects

this parameter;

4. the last three columns are the errors associated to T_{eff}, logg and v_t respectively. If the parameters are optimized spectroscopically, these uncertainties are ignored (you can also put 0 for all of them, as in the shown case); on the other hand, if a given parameter is fixed and the uncertainties with the classical method are requested (uncer=2 in autofl.param), these values are used to vary each parameter computing again the abundances. If in the input file the parameter uncertainties are 0 but you request to calculate the abundance uncertainties, the steps used to investigate the parameter space (and defined by the keywords stepteff, stepgr and stepvt among the basic parameters in autofl.param) are assumed as parameter errors.

- if you adopted grc= 2, the input file will be

```
ngc1806_25  4000   0.7  -0.5   2.0   0.0   0  0  0  -13.0
ngc1806_27  4200   1.2  -0.5   2.0   0.0   0  0  0  -13.2
ngc1806_29  4100   1.0  -0.5   2.0   0.0   0  0  0  -13.1
ngc1806_30  4400   1.5  -0.5   2.0   0.0   0  0  0  -13.2
ngc1806_32  4100   1.0  -0.5   2.0   0.0   0  0  0  -13.2
ngc1806_40  4100   0.8  -0.5   2.0   0.0   0  0  0  -13.4
```

Fig. 2.— Example of the list_star file when the option grc=2 is selected.

The additional tenth column ϵ is calculated according to the Stefan-Boltzmann equation as $\epsilon = \log(4\text{GM}\pi\sigma/\text{L})$, where G is the gravitational constant, σ the Boltzmann constant and M and L are the mass and the luminosity of the star. In this case the surface gravity will be calculated as logg= $\epsilon + 4 \cdot \log T_{\text{eff}}$

- if you adopted grc= 3, the input file will be

```
ngc1806_25  4000   0.7  -0.5   2.0   0.0   0  0  0  -7.69087  0.00198  0
ngc1806_27  4200   1.2  -0.5   2.0   0.0   0  0  0  -7.69087  0.00198  0
ngc1806_29  4100   1.0  -0.5   2.0   0.0   0  0  0  -7.69087  0.00198  0
ngc1806_30  4400   1.5  -0.5   2.0   0.0   0  0  0  -7.69087  0.00198  0
ngc1806_32  4100   1.0  -0.5   2.0   0.0   0  0  0  -7.69087  0.00198  0
ngc1806_40  4100   0.8  -0.5   2.0   0.0   0  0  0  -7.69087  0.00198  0
```

Fig. 3.— Example of the list_star file when the option grc=3 is selected.

where A, B and C are the coefficients of the quadratic relation log g= A+B·T_{eff}+C·T_{eff}^2.

5.3. Linelist file

For each star (specified by the <rootfilename> in the star_list file) an input file <rootfilename>.in is needed. If the linelist file of a given star listed in list_star is not available in the directory,

GALA provides a warning message and moves to the next star. Fig. 4 shows an example of a linelist input file for GALA. Note that this file does not need a specific numeric format, but it must contain the following information for each measured line:

- the wavelength (expressed in Å);

- the observed EW (expressed in mÅ);

- the uncertainty in EW (expressed in mÅ);

- the code of the element in the usual Kurucz notation;

- the logarithm of the oscillator strength;

- the excitation potential (expressed in eV);

- the logarithm of the radiative damping constant, γ_{rad} [10];

- the logarithm of the Stark damping constant, γ_{stark};

- the logarithm of the Van der Waals damping constant, γ_{VdW};

- the velocity parameter α as defined by Barklem et al. (2000) and usually available for many metallic lines both in the Kurucz/Castelli linelist and VALD databases. If the parameter α is not available for a given line, the value can be substituted with 0.

```
5403.8220   124.80    4.040   26.00  -1.03  4.076   7.84  -5.89  -7.73   0.00
5406.7750    65.30    3.610   26.00  -1.46  4.371   8.24  -4.50  -7.19   0.28
5408.9400   216.60   11.980   22.00  -3.84  0.000   6.23  -6.16  -7.74   0.25
5410.9100   140.70    4.550   26.00   0.40  4.473   8.10  -5.29  -7.13   0.28
5412.7860    49.80    4.040   26.00  -1.72  4.434   8.23  -5.16  -7.15   0.28
5426.2500    89.10    5.090   22.00  -3.01  0.021   6.23  -6.16  -7.73   0.25
5429.1380   113.30    6.080   22.00  -0.44  2.345   8.08  -6.04  -7.77   0.00
5436.2960    62.10    4.230   26.00  -1.51  4.386   8.24  -4.61  -7.19   0.28
5445.0420   134.20    4.220   26.00  -0.02  4.386   8.25  -4.86  -7.19   0.28
5453.6430   111.40    3.540   22.00  -1.61  1.443   7.98  -6.10  -7.79   0.00
5460.8730    47.30    4.410   26.00  -3.58  3.071   7.11  -6.20  -7.81   0.26
5461.5500    60.90    3.790   26.00  -1.64  4.446   8.27  -4.94  -7.16   0.28
5462.4850    51.00    4.110   28.00  -0.93  3.847   8.21  -4.06  -7.22   0.28
5463.2760   130.80    4.930   26.00   0.07  4.434   8.21  -4.97  -7.17   0.28
5473.9010   107.50   21.710   26.00  -0.79  4.154   8.37  -6.20  -7.27   0.24
5490.1480   140.60    4.870   22.00  -0.93  1.460   8.16  -5.99  -7.56   0.26
5491.8310    18.80    4.120   26.00  -2.19  4.186   8.22  -5.90  -7.74   0.00
5496.5620    13.90    4.370   26.00  -1.73  4.913   8.70  -5.08  -7.35   0.27
5503.8950    91.70    4.270   22.00   0.02  2.578   8.24  -6.05  -7.55   0.25
5512.9800   141.70    6.140   20.00  -0.45  2.932   8.52  -4.05  -7.36   0.00
5525.5440    98.00    6.950   26.00  -1.08  4.230   8.38  -5.89  -7.26   0.24
5528.8980    50.90    4.270   26.00  -2.02  4.473   8.22  -4.94  -7.16   0.28
5529.1600    58.20    3.930   26.00  -2.68  3.642   7.25  -6.30  -7.59   0.24
5536.5800    41.30    4.070   26.00  -3.73  2.832   7.26  -6.14  -7.82   0.26
5543.9360    98.90    4.760   26.00  -1.11  4.217   8.38  -5.87  -7.26   0.24
5546.5060    78.40    3.690   26.00  -1.28  4.371   8.25  -5.40  -7.22   0.28
5550.6090    24.60    2.890   72.00  -1.90  0.000   0.00   0.00   0.00   0.00
5551.3330     7.70    2.840   41.00  -1.44  0.620   0.00   0.00   0.00   0.00
```

Fig. 4.— Example of the linelist input file (<rootfilename>.in) for GALA.

---

[10]When one of the γ constants is 0, WIDTH9 calculates its value adopting some theoretical relations (see Castelli 2005b, for more details).

6.   Output files

For each star listed in the file list_star, GALA will create three output files.

(1) <rootfilename>.abu summarizes the derived parameters, the uncertainties and the mean abundance for each element available in the input file <rootfilename>.in. Fig. 5 shows an example of this kind of output file. The first thirteen lines are referred to the adopted analysis:

- the second line is the value of the merit function, that provides an estimate of the goodness of the solution;

- third, fourth and fifth lines concern the correlation among the lines in the A(El)–EWR , A(El)—χ_{ex} and A(El)—λ planes, summarysing the slope, the Jackknife uncertainty in the slope, the formal error in the slope, the Spearman rank correlation coefficient and the zero-point of the linear fit;

- the sixth line is the difference between the average abundances of the chosen element derived from neutral and single ionized lines, together with its Jackknife uncertainty;

- the seventh line is a flag (Optimization) about the adopted procedure: 'Optimization 1' indicates that the analysis has been performed as specified in autofl.param, while 'Optimization 0' advises that during the analysis the optimization of one or more parameters has been switched off. The following three lines specify as log g, $T_{\rm eff}$ and v_t have been optmized. The Optimization flag is useful to identify rapidly stars for which the analysis has had some problems or failures.

- The final atmospheric parameters are written in the twelfth line, together with the adopted model atmosphere (i.e. 'atlas9', 'marcs' or the name of the used individual model). In case of ATLAS9 models, if some atmospheric layers of the final model atmosphere do not converge (according to the convergence criteria proposed by Castelli 1988), the number of unconverged layers is specified. Also, the label PARAMETERS allows to easily extract the final parameters (for instance with grep or awk commands).

- The uncertainties in the parameters are written in the thirteenth line; at the end of the line, the parameters of the model atmospheres obtained with the procedure described by Cayrel et al. (2004) are reported (only if the option uncer= 1 or 2 is used and $T_{\rm eff}$ has been spectroscopically optimized). Note that these uncertainties in the atmospheric parameters are calculated by using the Jackknife technique for the optimized parameters: when a parameter

is fixed, the uncertainty is that provided by you in `list_star`, if the latter is 0, the step of the grid is taken as representative of the error.

- The following lines provide for each element the mean abundance, the dispersion of the mean, the number of used lines, the net variation of the abundance by using the two models obtained with the Cayrel et al. (2004) method (columns '+Cay' and '-Cay') and the net variation of the abundance by varying each time one only parameter (columns '+Teff', '-Teff', '+logg', '-logg', '+vt', '-vt'). Additionally, a summary file (named `abundance.final`) is provided, including all the <rootfilename>.abu files for the stars listed in `list_star`;

```
#                    ngc1806_25
#                    ngc1806_25      0.57      MERIT FUNCTION
#                    ngc1806_25      0.68795E-03     0.56919E-02     0.28138E-02     0.66353E-01     0.68909E+01  - Ab-EP  slope / Jack / Error / Spear / ZP
#                    ngc1806_25      0.53856E-02     0.46991E-01     0.19602E-01     0.44456E-01     0.69205E+01  - Ab-EW  slope / Jack / Error / Spear / ZP
#                    ngc1806_25     -0.52431E-05     0.30729E-04     0.12376E-04    -0.23669E+00     0.69258E+01  - Ab-WL  slope / Jack / Error / Spear / ZP
#                    ngc1806_25     -0.0269    0.0490   - <NEUTR-ION> / Jack
#                    ngc1806_25   Optimization  1
#                    ngc1806_25   GRAVITY FROM Fe I
#                    ngc1806_25   Teff FROM Fe I  (slope)
#                    ngc1806_25   Vt FROM Fe I  (slope)
        ngc1806_25   TEFF   LOGG    VT    [M/H]   alfa
        ngc1806_25   3950   0.70   1.60  -0.50   0.00  PARAMETERS  atlas9
        ngc1806_25     25   0.12   0.07          UNCERTAINTIES    3980/0.70/-0.50/1.6  ---  3920/0.60/-0.50/1.6
        ngc1806_25   code    mean sigma  Nlin    +Cay    -Cay    +Teff   -Teff   +logg   -logg    +vt     -vt
        ngc1806_25   26.00   6.89  0.10  104     0.00   -0.02    0.00    0.00    0.03   -0.03   -0.02    0.02
        ngc1806_25   26.01   6.92  0.12    9    -0.06   -0.01   -0.06    0.06    0.08   -0.09   -0.01    0.01
        ngc1806_25   11.00   5.61  0.04    2     0.03   -0.03    0.03   -0.03    0.00    0.00   -0.02    0.02
        ngc1806_25   12.00   7.27  0.06    2     0.00   -0.01    0.00    0.01    0.02   -0.02   -0.01    0.01
        ngc1806_25   13.00   5.98  0.04    2     0.02   -0.02    0.02   -0.02    0.00    0.00   -0.01    0.01
        ngc1806_25   14.00   7.12  0.14   13    -0.03    0.00   -0.03    0.03    0.04   -0.04   -0.01    0.01
        ngc1806_25   20.00   5.75  0.03    1     0.03   -0.03    0.03   -0.03    0.00    0.00   -0.01    0.01
        ngc1806_25   21.01   2.55  0.06    1    -0.01   -0.03   -0.01    0.01    0.05   -0.05   -0.03    0.03
        ngc1806_25   22.00   4.38  0.14   21     0.05   -0.05    0.05   -0.05    0.01    0.00   -0.02    0.02
        ngc1806_25   23.00   3.49  0.14    9     0.05   -0.06    0.05   -0.05    0.01   -0.01   -0.01    0.01
        ngc1806_25   24.00   5.11  0.12    5     0.02   -0.02    0.02   -0.02    0.00    0.00   -0.01    0.01
        ngc1806_25   27.00   4.43  0.09    5     0.00   -0.03    0.00    0.00    0.04   -0.04   -0.03    0.03
        ngc1806_25   28.00   5.47  0.09   21    -0.01   -0.02   -0.01    0.01    0.04   -0.03   -0.02    0.02
        ngc1806_25   39.00   1.38  0.09    2     0.06   -0.06    0.06   -0.06    0.00    0.00    0.00    0.00
        ngc1806_25   39.01   1.57  0.08    1    -0.01   -0.03   -0.01    0.01    0.05   -0.05   -0.01    0.01
        ngc1806_25   40.00   2.24  0.23   15     0.06   -0.06    0.06   -0.05    0.01   -0.01   -0.01    0.01
        ngc1806_25   41.00   0.00  0.00    0     0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
        ngc1806_25   42.00   1.51  0.10    4     0.04   -0.05    0.04   -0.04    0.01   -0.01   -0.01    0.01
        ngc1806_25   58.01   1.54  0.04    1     0.00   -0.04    0.00    0.00    0.05   -0.05   -0.01    0.01
        ngc1806_25   59.01   0.43  0.07    3     0.00   -0.04    0.00    0.00    0.05   -0.05    0.00    0.01
        ngc1806_25   60.01   1.28  0.09   13     0.01   -0.05    0.01   -0.01    0.05   -0.05   -0.01    0.01
        ngc1806_25   63.01   0.31  0.03    1    -0.01   -0.04   -0.01    0.01    0.05   -0.05   -0.01    0.01
        ngc1806_25   70.00   0.51  0.09    1     0.06   -0.06    0.06   -0.06    0.00    0.00    0.00    0.00
        ngc1806_25   72.00   0.37  0.06    1     0.05   -0.07    0.05   -0.05    0.02   -0.02    0.00    0.01
```

Fig. 5.— Example of the output file (<rootfilename>.abu) including information about atmospheric parameters, uncertainties and average abundances.

(2) <rootfilename>.EW includes the main information for each transition included in the input file <rootfilename>.in. Fig. 6 shows a part of this file as reference. The first rows of the file explain the meaning of the flag about the line rejection. Briefly:

flag = 1 the line is used;

flag = 0 the line is rejected according to the σ-clipping algorithm (see Mucciarelli et al. 2013);

flag = –1 the line is rejected because outside the range of valid EWR values specified by 'ewmin' and 'ewmax' in 'autofl.param';

flag = –2 the line is rejected because its error is larger than the boundary value 'error' in `autofl.param`;

flag = –3 if the abundance calculation performed by WIDTH9 does not converge, producing a 'NaN', the value is substituted with 99.999 and the line excluded by the analysis.

The rest of the file includes for each transition:

- the wavelength (expressed in Å);

- the observed EW (expressed in mÅ);

- the logarithm of the oscillator strength;

- the excitation potential (expressed in eV);

- the derived abundance;

- the error of EW, if provided in input (expressed in mÅ) ;

- the error in abundance obtained by varying the observed EW of $+1\sigma_{EW}$;

- the code of the element in the usual Kurucz notation;

- the flag related to the line rejection;

- the theoretical EW (expressed in mÅ) calculated by WIDTH9 through Gaussian integration of the line profile by using the nominal metallicity of the best model (see Castelli 2005b, for details);

- the net abundance variation calculated according to the method described by Cayrel et al. (2004) and keeping fixed the effective temperature at $T_{\rm eff} + \sigma T_{\rm eff}$ and $T_{\rm eff} - \sigma T_{\rm eff}$;

- the net abundance variations due to the variation of each parameter ($\pm\sigma T_{\rm eff}$,$\pm\sigma\log$ g, $\pm\sigma v_t$).

```
#   FLAG=1   (USED LINES)
#   FLAG=0  ( REJ. SIGMA-CLIPPING)
#   FLAG=-1 (REJ. EW)
#   FLAG=-2 (REJ. ERROR)
#   FLAG=-3 (NaN)
#
#   WAVE(A)   EW(mA)   loggf   EP(eV)   Abu   errEW(mA)  errAbu  CODE   FLAG  EWtheo(mA)  +Cay    -Cay    +Teff   -Teff   +logg   -logg    +vt    -vt
    5403.822  124.80  -1.030   4.080   7.392   4.04     0.09   26.00   -1.   107.42   -0.008  -0.011  -0.008   0.010   0.028  -0.027  -0.059   0.063
    5406.775   65.30  -1.460   4.370   6.940   3.61     0.07   26.00    1.    68.40   -0.008  -0.011  -0.008   0.010   0.027  -0.026  -0.021   0.022
    5410.910  140.70   0.400   4.470   6.718   4.55     0.07   26.00   -1.   160.11   -0.006  -0.001  -0.006   0.006   0.008  -0.010  -0.045   0.042
    5412.786   49.80  -1.720   4.430   6.990   4.04     0.08   26.00    1.    50.34   -0.006  -0.011  -0.006   0.008   0.026  -0.025  -0.012   0.014
    5436.296   62.10  -1.510   4.390   6.947   4.23     0.08   26.00    1.    64.85   -0.008  -0.011  -0.008   0.010   0.029  -0.026  -0.019   0.020
    5445.042  134.20  -0.020   4.390   6.875   4.22     0.07   26.00   -1.   141.73   -0.006  -0.005  -0.006   0.008   0.016  -0.016  -0.043   0.044
    5460.873   47.30  -3.580   3.070   6.901   4.41     0.08   26.00    1.    52.93    0.004  -0.025   0.004  -0.003   0.029  -0.028  -0.010   0.011
    5461.550   60.90  -1.640   4.450   7.136   3.79     0.07   26.00    1.    53.80   -0.009  -0.010  -0.009   0.010   0.027  -0.025  -0.018   0.019
    5463.276  130.80   0.070   4.430   6.796   4.93     0.09   26.00   -1.   142.97   -0.007  -0.004  -0.007   0.009   0.016  -0.016  -0.044   0.047
    5473.901  107.50  -0.790   4.150   6.798  21.71     0.41   26.00   -2.   117.93   -0.008  -0.011  -0.008   0.009   0.026  -0.026  -0.042   0.043
    5491.831   18.80  -2.190   4.190   6.450   4.12     0.11   26.00   -2.    43.68   -0.001  -0.018  -0.001   0.001   0.024  -0.024  -0.003   0.003
    5496.562   13.90  -1.730   4.910   6.805   4.37     0.15   26.00   -2.    19.95   -0.005  -0.012  -0.005   0.005   0.022  -0.021  -0.002   0.002
    5525.544   98.00  -1.080   4.230   6.997   6.95     0.14   26.00    1.    98.16   -0.007  -0.009  -0.007   0.011   0.029  -0.027  -0.037   0.039
    5528.898   50.90  -2.020   4.470   7.361   4.27     0.08   26.00    0.    32.52   -0.007  -0.011  -0.007   0.009   0.027  -0.025  -0.013   0.014
    5529.160   58.20  -2.680   3.640   7.000   3.93     0.07   26.00    1.    58.21   -0.002  -0.018  -0.002   0.002   0.030  -0.028  -0.015   0.017
    5536.580   41.30  -3.730   2.830   6.600   4.07     0.07   26.00    1.    64.09   -0.006  -0.028   0.006  -0.005   0.030  -0.028  -0.007   0.008
    5543.936   98.90  -1.110   4.220   7.026   4.76     0.09   26.00    1.    97.71   -0.009  -0.012  -0.009   0.008   0.026  -0.029  -0.038   0.037
    5546.506   78.40  -1.280   4.370   7.010   3.69     0.07   26.00    1.    77.97   -0.011  -0.011  -0.011   0.010   0.027  -0.028  -0.029   0.028
    5560.212   71.10  -1.160   4.430   6.833   3.34     0.07   26.00    1.    79.54   -0.010  -0.010  -0.010   0.012   0.029  -0.027  -0.024   0.026
    5576.089   52.80  -0.940   3.430   4.856   4.39     0.08   26.00    0.   167.15    0.001  -0.021   0.001   0.001   0.029  -0.028  -0.013   0.014
    5577.025   16.00  -1.550   5.030   6.857   3.67     0.11   26.00   -2.    20.72   -0.006  -0.011  -0.006   0.007   0.023  -0.021  -0.002   0.002
    5579.341  118.00  -2.400   4.230   8.691   4.32     0.08   26.00   -1.    30.36   -0.008  -0.010  -0.008   0.009   0.025  -0.025  -0.042   0.044
    5611.356    5.10  -2.990   3.630   5.853   3.06     0.22   26.00   -1.    42.16    0.004  -0.023   0.004  -0.002   0.027  -0.024   0.000   0.001
    5633.946   66.40  -0.320   4.990   6.652   3.14     0.06   26.00    1.    85.05   -0.014  -0.005  -0.014   0.017   0.027  -0.027  -0.019   0.021
    5636.696   69.20  -2.560   3.640   7.076   3.50     0.07   26.00    1.    65.23   -0.004  -0.019  -0.004   0.005   0.032  -0.031  -0.023   0.024
    5640.307   25.90  -1.700   4.640   6.754   2.75     0.06   26.00    1.    37.24   -0.005  -0.013  -0.005   0.006   0.025  -0.024  -0.003   0.004
    5642.751   31.90  -2.100   4.610   7.247   3.41     0.07   26.00    0.    21.49   -0.006  -0.013  -0.006   0.007   0.025  -0.024  -0.007   0.006
    5646.684   17.40  -2.500   4.260   6.813   1.81     0.05   26.00    1.    24.22   -0.016  -0.001  -0.016   0.003   0.026  -0.023  -0.002   0.003
    5650.690   43.70  -0.960   5.080   6.991   1.94     0.04   26.00    1.    44.18   -0.011  -0.007  -0.011   0.014   0.026  -0.025  -0.010   0.011
    5652.318   45.80  -1.920   4.260   6.868   2.77     0.05   26.00    1.    52.83   -0.005  -0.014  -0.005   0.008   0.028  -0.026  -0.011   0.012
    5653.867   67.30  -1.610   4.390   7.140   3.78     0.07   26.00    1.    60.07   -0.010  -0.011  -0.010   0.011   0.029  -0.029  -0.022   0.022
    5659.575   32.30  -1.230   5.080   7.028   3.55     0.08   26.00    1.    31.02   -0.009  -0.009  -0.009   0.011   0.025  -0.023  -0.007   0.007
    5660.801   49.60  -2.830   3.640   6.980   3.72     0.07   26.00    1.    50.78   -0.001  -0.021  -0.001   0.003   0.029  -0.029  -0.012   0.011
    5661.345   56.00  -1.760   4.280   6.932   3.07     0.06   26.00    1.    59.66   -0.008  -0.013  -0.008   0.009   0.028  -0.028  -0.016   0.016
    5662.516  133.70  -0.570   4.280   7.104   4.47     0.07   26.00   -1.   127.94   -0.008  -0.012  -0.008   0.009   0.027  -0.029  -0.049   0.046
    5678.601   89.60  -4.670   2.420   7.789   5.59     0.11   26.00    0.    44.41    0.006  -0.031   0.006  -0.004   0.035  -0.034  -0.032   0.034
    5686.530  103.30  -0.450   4.550   6.932   3.28     0.07   26.00    1.   106.69   -0.013  -0.009  -0.013   0.014   0.030  -0.030  -0.042   0.042
```

Fig. 6.— Example of the output file (`<rootfilename>.EW`) including information for each individual line.

(3) `<rootfilename>.ps` is the graphical output of GALA where the the main results are shown and an example of this output is shown in Fig. 7. The first three panels show the behaviour

of the abundances for the chosen element as a function of EWR, χ_{ex} and λ; the small lower panel in the first panel shows the behaviour of the EW error as a function of EWR. The blue lines are the linear fits obtained in each plane. The last panel shows the curve of growth obtained by plotting EWR as a function of the theoretical EW, defined as EWT= loggf - $\theta\chi_{ex}$.
Black points are the lines in the ionization stage used to optmize T_{eff} and v_t, while red points the lines of the same species but in the other ionization stage; for instance, if you specify 26.00 (Fe I) in the 'qiron' parameter, black points in the graphical output will be the neutral iron lines and the red points the Fe II lines. Empty points are the lines rejected during the analysis (the reason of the rejection is specified in the <rootfilename>.EW file).

7. How to manage the grids of model atmospheres

The automatization of the chemical analysis as implemented by GALA needs the management of wide grids of model atmospheres, in order to freely explore the parameter space. Here we briefly explain how you can obtain the grids of models. It is worth to recall that you do not need to download all the models described in the following: you can only have the grid of models that you will use for your analysis. The only caveat is that you cannot call a kind of model in the autofl.param file if you do not have a directory with all these models.

If you decide to adopt ATLAS9 models for your analysis, you need to create in the corresponding directory three sub-directories, named ODF/, MODELS/ and MODELS-new/ (the latter is empty and it will be filled with new models progressively using GALA).

Note that the capability to calculate a given ATLAS9 model atmosphere depends on the availability of the ODF computed with the requested chemical composition. The input guess model atmosphere has to be as close as possible to the new model in terms of T_{eff}, log g and metallicity in order to allow a good convergence, but in principle, the output model is independent from the input one. Thus, when a new ATLAS9 model is requested during the analysis process, GALA looks for the ODF and Rosseland table corresponding to the requested metallicity, if these tables do exist, the closest model with that chemical composition is picked as input guess model (GALA recognizes automatically the closest model), otherwise GALA skips the star and advises you with a warning message that the selected metallicity is incompatible with the metallicities encoded in GALA. The extension (in terms of metallicity, α-enhancement and microturbulent velocity) of each ATLAS9 grid is written in the source code of GALA, allowing an easy implementation of additional ATLAS9 grids in the next releases of GALA.

ATLAS9 (F.Castelli)
This dataset includes ODFs calculated for 5 values of microturbulent velocities (namely, 0, 1, 2, 4 and 8 km/s) and two levels of α-enhancement, [α/Fe]=0.0 and +0.4. GALA uses the metallicities between –5.5 and +0.5 dex with a step of 0.5. To easily obtain all the needed files, we provide a wget-based procedure. Move the code downl_fx.csh in the directory specified in the file
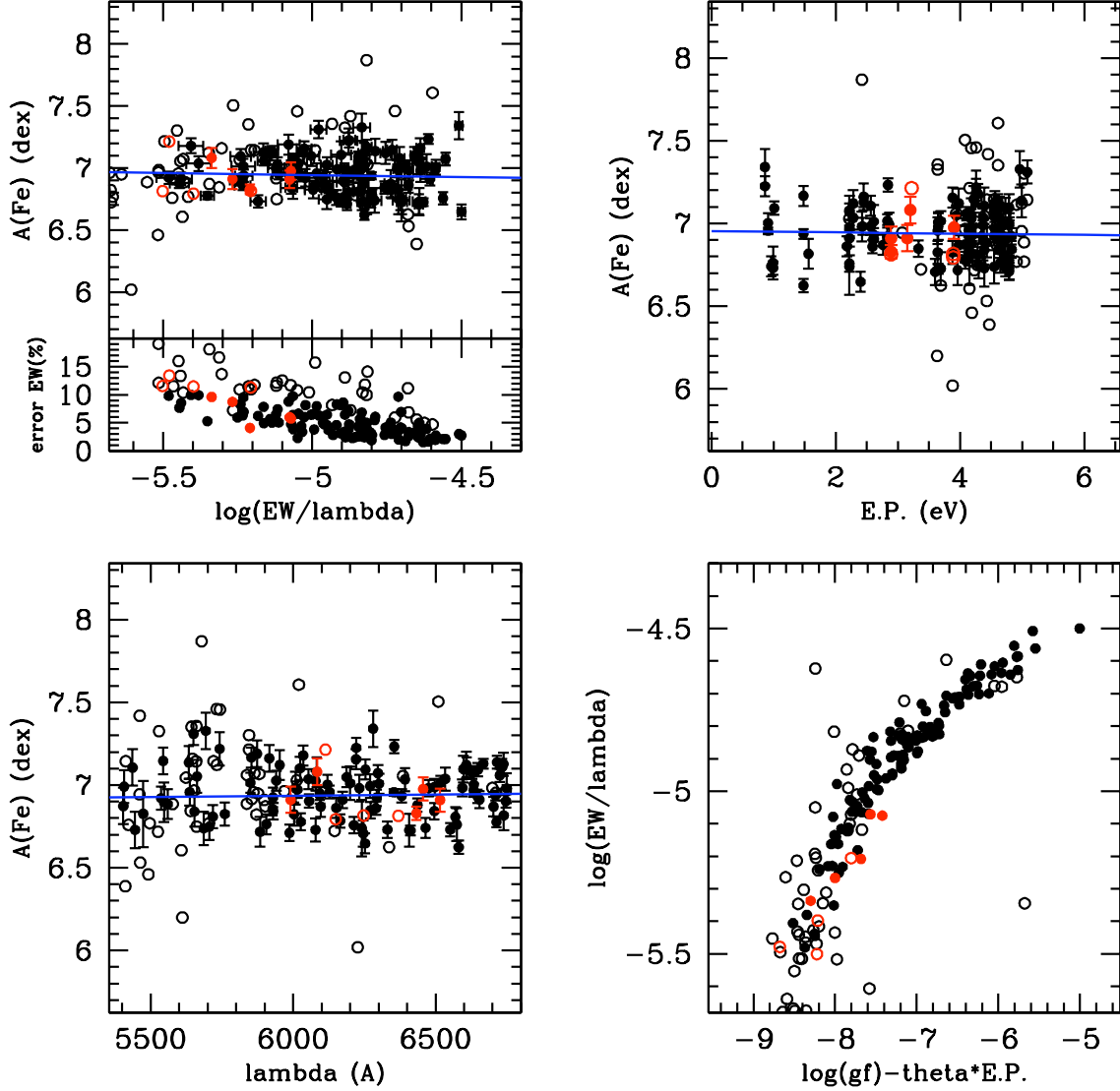
Fig. 7.— Example of the graphical output (<rootfilename>.ps) of GALA. Left-upper panel shows the behaviour of the abundances as a function of the reduced EW, EWR (while the small panel shows the behaviour of the EW error as a function of EWR). Right-upper and left-lower panels plot the behaviour of the abundances as a function of χ_{ex} and of the wavelength, respectively. The right-lower panel shows an empirical curve of growth. In all the panels the filled circles are the used lines and empty circles are the rejected lines. Black symbols are the lines used in the optimization of $T_{\rm eff}$ and v_t (Fe I in this case), while red symbols are the lines in the other ionization stage (Fe II in this case). Blue lines are the linear best-fits.

`GALA/src/Paths.f` and type

`./downl fc.csh`

However, in the following we describe the correct way to obtain and manage the ATLAS9 files.

1. In the directory specified in the file `GALA/src/Paths.f` for this grid of models, create three subdirectory, named `ODF`, `MODELS` and `MODELS-new`. In the first subdirectory, put ODFs and Rosseland tables with [M/H] between –5.5 and +0.5 dex (at step of 0.5) and with both the values of α-enhancement. You can download the ODFs from the website of F. Castelli

   http://wwwuser.oat.ts.astro.it/castelli/odfnew.html

   (you need only the *big* ODFs, do not download the *lit* ODFs), as well as the tables with the Rosseland mass absorption coefficients

   http://wwwuser.oat.ts.astro.it/castelli/kaprossnew.html.

2. The grids of models are available in the same website

   http://wwwuser.oat.ts.astro.it/castelli/grids.html.

   For the metallicities used by GALA, all the models of a given [M/H] are available in a single ASCII file (for instance, master file for [M/H]=+0.5 and [α/Fe]= 0.0 is named `ap05k2odfnew.dat`, while for [M/H]=+0.5 and [α/Fe]= +0.4 `ap05ak2odfnew.dat`.) Save these (14) files in the subdirectory `MODELS`. We recommend to download these files (without renaming them), because GALA looks for these files to pick the input guess model (please, avoid downloading the grids with peculiar assumptions, as He enhancements and different mixing length values, because GALA does not (yet) use these grids to search for the input model). Note that when you ask GALA to use a metallicity outside the range –5.5/+0.5, the star will be analysed by adopting the closest model.

3. The new ATLAS9 models calculated during the runs of GALA will be saved in the subdirectory `MODELS-new`, together with a file including the main information about the calculation of the model. The new models will be named following the same formalism used by Castelli & Kurucz (2004) for the individual models; for instance, a model with $T_{\rm eff}$= 4120 K, log g= 1.32, v_{turb}=2 km/s, [M/H]=–0.5 and [α/Fe]= +0.4 will be saved as *am05at4120g132k2odfnew.dat*, will its summary file will be named *am05at4120g132k2.log_at9*.

ATLAS9 (APOGEE)
Recently, Meszaros et al. (2012) computed a new set of ATLAS9 model atmospheres, ODFs and Rosseland opacity tables, spanning a huge range of metallicity, α-enhancement and C abundances.

In order to avoid the introduction of another input parameter (namely the C abundance, [C/Fe]), GALA uses subgrids with fixed C abundances. The models (as well as the ODFs and the Rosseland opacity tables) are freely available from the website

http://www.iac.es/proyecto/ATLAS-APOGEE/

Note that if you plan to use only the models with a given [C/Fe] value, you can easily download only the desired files or download all the models and ODFs and then delete these not of interest (in order save disk space). In following we describe how to obtain all the models but the same instructions are valid also to manage ODFs and models for a given [C/Fe] value.

1. Also for the ATLAS9-APOGEE grid, create in the corresponding directory three subdirectories named `ODF`, `MODELS` and `MODELS-new`. On the webpage, the available data are provided in `tar.bz2` archive files according to the metallicity. Download the ODFs archive files.

2. The archive file including all the models (and named `all_mod.tar`) is available on the main page of the ATLAS9-APOGEE project. Download this file in your subdirectory `MODELS/` and unpack it. The archive includes for each chemical composition a subdirectory with all the individual models and a master file grouping together all the models of that chemical composition. Delete all these subdirectories and leave only the master files. These files are named according to the chemical composition: for instance, `mm05cm03op00.mod` is the master file including all the models with [M/H]=–0.5, [C/Fe]=-0.25 and [α/Fe]=+0.0). Do not rename neither the models nor the ODFs, otherwise GALA will crash because it will be not able to find the needed files to calculate a model atmosphere.

3. The new ATLAS9 models will be saved in the subdirectory `MODELS-new`. Also for the ATLAS9-APOGEE models, new models and summary files will be named according to the nomenclature used to label the original model of the grids. Also for the models, do not rename the files. For instance, the model with $T_{\rm eff}$= 4120 K, log g= 1.32, v_{turb}=2 km/s, [M/H]=–0.5, [C/Fe]=-0.25 and [α/Fe]= +0.0 will be named `amm05cm03op00t4120g132v20.mod`.

MARCS

MARCS model atmospheres are available at the website

http://marcs.astro.uu.se/

but unfortunately the entire grid of models cannot be downloaded as a whole, because the web-interface allows to download a limited (less than an hundred) number of models at a time. If you wish to use the MARCS models, he/she needs to patiently download all the models from the website and then group them according to their metallicity, microturbulent velocity (as done for the ATLAS9 grids) and geometry (plane-parallel or spherical). GALA is designed to manage only

the grids with standard chemical composition and microturbulent velocities 1 and 2 km/s, but modified versions of the code can be provided on request for other sub-grids of MARCS models. Because the grid of models with standard chemical composition naturally varies the α-enhancement according to the metallicity, for these models it is not necessary to group them for the value of the α-enhancement, at variance with the ATLAS9 models. Each master file needs to have a precise name. In Fig. 8 we summarize the name of these master files, as expected by GALA, together with the corresponding metallicity and geometry, and the total number of included models.

```
marcs_p100k1.pp    [M/H]= +1.00    vturb=1 km/s    plane-parallel    171    models
marcs_p100k2.sp    [M/H]= +1.00    vturb=2 km/s    spherical         210    models
marcs_p075k1.pp    [M/H]= +0.75    vturb=1 km/s    plane-parallel    172    models
marcs_p075k2.sp    [M/H]= +0.75    vturb=2 km/s    spherical         219    models
marcs_p050k1.pp    [M/H]= +0.50    vturb=1 km/s    plane-parallel    174    models
marcs_p050k2.sp    [M/H]= +0.50    vturb=2 km/s    spherical         217    models
marcs_p025k1.pp    [M/H]= +0.25    vturb=1 km/s    plane-parallel    172    models
marcs_p025k2.sp    [M/H]= +0.25    vturb=2 km/s    spherical         226    models
marcs_p000k1.pp    [M/H]= +0.00    vturb=1 km/s    plane-parallel    173    models
marcs_p000k2.sp    [M/H]= +0.00    vturb=2 km/s    spherical         232    models
marcs_m025k1.pp    [M/H]= -0.25    vturb=1 km/s    plane-parallel    173    models
marcs_m025k2.sp    [M/H]= -0.25    vturb=2 km/s    spherical         225    models
marcs_m050k1.pp    [M/H]= -0.50    vturb=1 km/s    plane-parallel    173    models
marcs_m050k2.sp    [M/H]= -0.50    vturb=2 km/s    spherical         220    models
marcs_m075k1.pp    [M/H]= -0.75    vturb=1 km/s    plane-parallel    168    models
marcs_m075k2.sp    [M/H]= -0.75    vturb=2 km/s    spherical         211    models
marcs_m100k1.pp    [M/H]= -1.00    vturb=1 km/s    plane-parallel    168    models
marcs_m100k2.sp    [M/H]= -1.00    vturb=2 km/s    spherical         210    models
marcs_m150k1.pp    [M/H]= -1.50    vturb=1 km/s    plane-parallel    162    models
marcs_m150k2.sp    [M/H]= -1.50    vturb=2 km/s    spherical         202    models
marcs_m200k1.pp    [M/H]= -2.00    vturb=1 km/s    plane-parallel    161    models
marcs_m200k2.sp    [M/H]= -2.00    vturb=2 km/s    spherical         187    models
marcs_m250k1.pp    [M/H]= -2.50    vturb=1 km/s    plane-parallel    165    models
marcs_m250k2.sp    [M/H]= -2.50    vturb=2 km/s    spherical         190    models
marcs_m300k1.pp    [M/H]= -3.00    vturb=1 km/s    plane-parallel    136    models
marcs_m300k2.sp    [M/H]= -3.00    vturb=2 km/s    spherical         165    models
marcs_m400k1.pp    [M/H]= -4.00    vturb=1 km/s    plane-parallel    123    models
marcs_m400k2.sp    [M/H]= -4.00    vturb=2 km/s    spherical         132    models
marcs_m500k1.pp    [M/H]= -5.00    vturb=1 km/s    plane-parallel    108    models
marcs_m500k2.sp    [M/H]= -5.00    vturb=2 km/s    spherical         117    models
```

Fig. 8.— List of the files with the MARCS models grouped according to their metallicity, microturbulent velocities and geometry.

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