1. A brief description of the package

The three main scripts included in the package are:

→ **stspars.R**: selects stellar parameters along a isochrone defining a population with a given age, [Fe/H] and [α/Fe]. The output is a text file containing a list of stellar parameters.

→ **pfant12.R:** reads the output from **`stspars`** and calls the code PFANT to calculate the synthetic stellar spectra for each pair of $T_{\rm eff}$, log g. Different [C, N, O, Mg, Si, Ca, Ti, Na/Fe] abundance ratios can be defined.

→ **SSP_model.R:** reads the output from **`stspars`** and the corresponding synthetic spectra calculated by **`pfant12`**, and creates the SSP spectra by adding the stellar spectrum weighted by the number of stars at each position in the HR-diagram, which is given by the IMF.

The script example.R shows how to use these functions to calculate a synthetic SSP spectra.

2. Description of the functions

stpars (stpars.R)

NAME:
   stpars

PURPOSE:
   Get stellar parameters from Darthmouth
   (http://stellar.dartmouth.edu/models/index.html) stellar evolutionary tracks

CALLING SEQUENCE:
   > source(stpars.R)
   > stpars(n_ms, n_hb, feh, afe, age, fig)

PARAMETERS:
   n_ms = number of desired main sequence stars
   n_hb = number of desired red giant stars
   feh = iron abundance [Fe/H] (available [Fe/H] range is -0.5 -> 0.5)
   afe = [α/Fe] (available values -0.2, 0.0, +0.2, +0.4, +0.6, +0.8;
          → [α/Fe] = +0.4, +0.6, +0.8 -> available only for [Fe/H] <= 0)
   age = age of the population (Gyr; available ages: 1.00 1.25 1.50 1.75 2.00
          2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.5 6.0
          6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5 13.0
          13.5 14.0 14.5 15.0 Gyr)
   fig = logical; if set, the isochrone is plotted

OUTPUT:
   Text file containing the stellar parameters (T_{eff}, logg, Mass, log[$L/L_{\odot}$]) of
     (n_ms + n_hb + 1) stars

REQUIRED ROUTINES:
   ./atm_models/iso_interp_feh (fortran code)
   ./atm_models/isolf_split (fortran code)
   (codes from http://stellar.dartmouth.edu/models/programs.html)

DESCRIPTION:
   The function stpars selects (n_ms + n_hb + 1) pairs of [log g, T_{eff}] along the
   isochrone. The effective temperatures of the selected MS and RGB stars are
   spaced by
     $^{MS}\Delta T_{eff} \sim (^{MS}T_{eff\_max} - {}^{MS}T_{eff\_min}) / n\_ms$
      and
     $^{RG}\Delta T_{eff} \sim (^{RG}T_{eff\_max} - {}^{RG}T_{eff\_min}) / n\_rg.$

EXAMPLE:
   1. Select 16 (9 + 6 + 1) pairs of T_{eff}, logg along a 8 Gyr isochrone calculated
      for [Fe/H] = 0.2 and [α/Fe] = 0.2, and plot the isochrone

      >> stpars(9, 6, 0.2, 0.2, 8, fig = T)

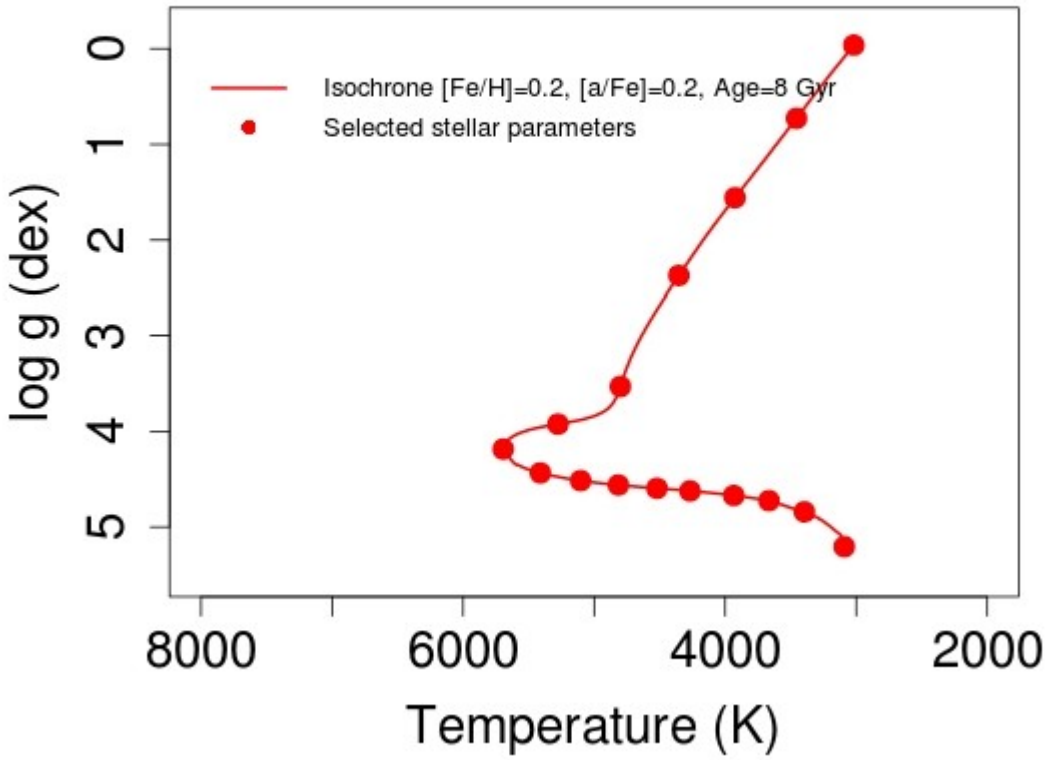

Figure 1: Plot from Example 1 of stpars

pfant12 (pfant12.R)

NAME:
   pfant12

PURPOSE:
   Calculate the synthetic stellar spectra for a list of stellar parameters using
   the PFANT code

CALLING SEQUENCE:
   > source('pfant12.R')
   > pfant12(feh, afe, lmin, lmax, age, vt, fwhm, dl, CFe, NFe, OFe, MgFe, SiFe,
CaFe, TiFe, NaFe, n_ms, n_rg, parfile)

PARAMETERS:
   feh = iron abundance [Fe/H] (available [Fe/H] range is -0.5 -> 0.5)
   afe = [α/Fe]
   lmin = lower lambda
   lmax = upper lambda
   age = age of the isochrone (Gyr)
   vt   = microturbulence velocity (default = 2.0 km/s)
   fwhm = spectral resolution (default = 0.2 A)
   dl   = sampling delta lambda (default = 0.1 A/pixel)
   CFe = [C/Fe] (set to 0.0 if omitted, i.e., default [C/Fe] = solar)
   NFe = [N/Fe] (set to 0.0 if omitted, i.e., default [N/Fe] = solar)
   OFe = [O/Fe] (set to [α/Fe] if omitted, i.e., default [O/Fe] = afe)
   MgFe = [Mg/Fe] (set to [α/Fe] if omitted, i.e., default [Mg/Fe] = afe)
   SiFe = [Si/Fe] (set to [α/Fe] if omitted, i.e., default [Si/Fe] = afe)
   CaFe = [Ca/Fe] (set to [α/Fe] if omitted, i.e., default [Ca/Fe] = afe)
   TiFe = [Ti/Fe] (set to a[α/Fe]fe if omitted, i.e., default [Ti/Fe] = afe)
   NaFe = [Na/Fe] (set to 0.0 if omitted, i.e., default [Na/Fe] = solar)
   n_ms = number of main sequence stars
   n_rg = number of red giant stars
   parfile = file with list of stellar parameters (used only if n_ms/n_rg are not
             specified)

INPUT:
   Text file containing a list of stellar parameters (T_{eff}, logg, Mass, log[$L/L_{\odot}$]).

OUTPUT:
   Synthetic stellar spectra in folder ./Stellar_Spectra/ (4 files for each pair
     of T_{eff}, logg)
   logfile: pfant12.log

REQUIRED ROUTINES:
   pfantgrade (PFANT fortran code)
   nulbadegrade (fortran code)
   hydro2 (fortran code)
   innewmarcs2 (fortran code):
       ./atm_models/innewmarcs2_grid_dwarfs2
       ./atm_models/innewmarcs2_grid_giants_g_gt_1
       ./atm_models/innewmarcs2_grid_giants_g_lt_1
   set.stpars.filename (R function, defined in stpars.R)

DESCRIPTION:

This function reads the output file from stpars (or a file in the same format) containing a list of stellar parameters (T_{eff}, logg, Mass, log[$L/L_{\odot}$]) and calls the code PFANT to calculate the synthetic stellar spectra for each pair of T_{eff}, logg.

The PFANT code:

The code is described in Cayrel et al. 1991, A&A, 247, 108 ; Barbuy et al. 2003, A&A, 404, 661 ; and Coelho et al. 2005, A&A, 443, 735 . Given a stellar model atmosphere and lists of atomic and molecular lines, the code computes a synthetic spectrum assuming local thermodynamic equilibrium (LTE). The atomic and molecular line lists included in this distribution correspond to the refined data calibrated through several stellar spectroscopic studies (see Barbuy et al. 2003, A&A, 404, 661).

The PFANT code take about 15 minutes to calculate a stellar spectrum from 3500 to 9000 A with 0.1 A/pixel (@Intel® Core™ i7-3630QM CPU @ 2.40GHz × 8; 8GB RAM).

Model atmospheres:

The pfant12 function uses MARCS 1D hydrostatic LTE atmospheric models (Gustafsson et al., 2008, A&A, 486, 951, http://marcs.astro.uu.se/).
The grids cover effective temperatures from 2600 to 8000 K and log g from -0.5 to 5.0. The following grids are used:

grid 1

- PLANE-PARALLEL
- Grid limits: 3.0 < logg < 5.0, 2900 < T_{eff} < 8000 K
- Associated files:
  - ./atm_models/marcs2009z-0.50_a+0.20_dwarfs2.mod
  - ./atm_models/marcs2009z-0.25_a+0.10_dwarfs2.mod
  - ./atm_models/marcs2009z+0.00_a+0.00_dwarfs2.mod
  - ./atm_models/marcs2009z+0.25_a+0.00_dwarfs2.mod
  - ./atm_models/marcs2009z+0.50_a+0.00_dwarfs2.mod
  - ./atm_models/innewmarcs2_grid_dwarfs2

grid 2

- SPHERICAL, mass = 1 $M_{\odot}$
- Grid limits: 1.0 < logg < 3.0, 2600 < T_{eff} < 5250 K
- Associated files:
  - ./atm_models/marcs2009z-0.50_a+0.20_giants_g_gt_1.mod
  - ./atm_models/marcs2009z-0.25_a+0.10_giants_g_gt_1.mod
  - ./atm_models/marcs2009z+0.00_a+0.00_giants_g_gt_1.mod
  - ./atm_models/marcs2009z+0.25_a+0.00_giants_g_gt_1.mod
  - ./atm_models/marcs2009z+0.50_a+0.00_giants_g_gt_1.mod
  - ./atm_models/innewmarcs2_grid_giants_g_gt_1

grid 3

- SPHERICAL, mass = 1 $M_{\odot}$
- Grid limits: -0.5 < logg < 1.0, 3300 < T_{eff} < 3900 K
- Associated files:
  - ./atm_models/marcs2009z-0.50_a+0.20_giants_g_lt_1.mod
  - ./atm_models/marcs2009z-0.25_a+0.10_giants_g_lt_1.mod
  - ./atm_models/marcs2009z+0.00_a+0.00_giants_g_lt_1.mod
  - ./atm_models/marcs2009z+0.25_a+0.00_giants_g_lt_1.mod
  - ./atm_models/marcs2009z+0.50_a+0.00_giants_g_lt_1.mod
  - ./atm_models/innewmarcs2_grid_giants_g_lt_1

If the stellar parameters T_{eff}, logg are off of the grid limits, a WARNING message is written in the pfant12.log file.

Only MARCS models with [Fe/H] = -0.50, -0.25, 0.00, +0.25, and +0.50 are included in this distribution. The abundance ratios for each [Fe/H] value are (the "standard metallicity class"; see http://marcs.astro.uu.se/ for details):

[Fe/H] = -0.50, [α/Fe] = +0.2, [C/Fe] = 0.0, [N/Fe] = 0.0, [O/Fe] = +0.2
[Fe/H] = -0.25, [α/Fe] = +0.1, [C/Fe] = 0.0, [N/Fe] = 0.0, [O/Fe] = +0.1
[Fe/H] = 0.00, [α/Fe] = 0.0, [C/Fe] = 0.0, [N/Fe] = 0.0, [O/Fe] = 0.0
[Fe/H] = +0.25, [α/Fe] = 0.0, [C/Fe] = 0.0, [N/Fe] = 0.0, [O/Fe] = 0.0
[Fe/H] = +0.50, [α/Fe] = 0.0, [C/Fe] = 0.0, [N/Fe] = 0.0, [O/Fe] = 0.0

The codes innewmarcs2* do not extrapolate the [Fe/H] grid (extrapolation is performed only for T_{eff} and logg). Therefore, spectra computed using this package are restricted to iron abundances -0.5 < [Fe/H] < +0.5. Any attempt to compute the synthetic stellar spectra with [Fe/H] > +0.5 or [Fe/H] < -0.5 will fail and result in an error message.

Solar abundances:
The reference solar abundances ($\log_{10}[N_X/N_H]$) must be specified in the file abonds_Sun.dat.

EXAMPLE:

1. Calculate the synthetic stellar spectra of 16 stars listed in the file ./Stellar_pars/stpars_fe+0.20a+0.20age08.0ms09rg08.dat, with [Fe/H] = 0.2, [a/Fe] = [O, Mg, Si, Ca, Ti/Fe] = 0.2, [C, N, Na/Fe] = 0.0, in the region from 6000 to 6500 A.

   ```
   >> pfant12(0.2, 0.2, 6000, 6500, 8, n_ms = 9, n_rg = 6)
   ```

2. Calculate the synthetic stellar spectra for the stellar parameters listed in the file "pars.txt", with [Fe/H] = 0.3, [a/Fe] = [O, Mg, Si, Ti/Fe] = 0.2, [Ca/Fe] = 0.0, [C, N, Na/Fe] = 0.0

   ```
   >> pfant12(0.3, 0.2, 6000, 6500, parfile = 'pars.txt', CaFe = 0.0)
   ```

ssp.model (SSP_model.R)

NAME:
   ssp.model

PURPOSE:
   Calculate SSP spectra

CALLING SEQUENCE:
   > source('SSP_model.R')
   > ssp.model(feh, afe, age, imf, slope, fwhm, dl, CFe, NFe, OFe, MgFe, SiFe, CaFe, TiFe, NaFe, n_ms, n_rg, parfile, lmin, lmax)

INPUTS:
   feh   = iron abundance [Fe/H]
   afe   = [α/Fe]
   age   = age of the isochrone (Gyr)
   imf   = IMF (Kroupa, Salpeter or Unimodal; Salpeter→ Unimodal with slope = 2.3)
   slope = IMF slope (if IMF = Unimodal)
   fwhm = spectral resolution (default = 0.2 A)
   dl   = sampling delta lambda (default = 0.1 A/pixel)
   CFe = [C/Fe] (set to 0.0 if omitted, i.e., default [C/Fe] = solar)
   NFe = [N/Fe] (set to 0.0 if omitted, i.e., default [N/Fe] = solar)
   Ofe   = [O/Fe] (set to [α/Fe] if omitted, i.e., default [O/Fe] = afe)
   MgFe = [Mg/Fe] (set to [α/Fe] if omitted, i.e., default [Mg/Fe] = afe)
   SiFe = [Si/Fe] (set to [α/Fe] if omitted, i.e., default [Si/Fe] = afe)
   CaFe = [Ca/Fe] (set to [α/Fe] if omitted, i.e., default [Ca/Fe] = afe)
   TiFe = [Ti/Fe] (set to a[α/Fe]fe if omitted, i.e., default [Ti/Fe] = afe)
   NaFe = [Na/Fe] (set to 0.0 if omitted, i.e., default [Na/Fe] = solar)
   n_ms = number of main sequence stars
   n_rg = number of red giant stars
   parfile = file with list of stellar parameters (used only if n_ms/n_rg are not
             specified)
   lmin = lower lambda
   lmax = upper lambda

INPUT:
   Text file containing a list of stellar parameters (T_{eff}, logg, Mass, log[$L/L_{\odot}$])
   Stellar spectra of the stars listed in the text file

OUTPUT:
   SSP spectra in folder ./SSP_Spectra/
   logfile in folder ./SSP_Spectra/

REQUIRED SCRIPTS:
   nulbadegrade (fortran code)
   set.stpars.filename (R function, defined in stpars.R)
   get.tracks   (R function, defined in stpars.R)
   set.stspec.filename (R function, defined in pfant12.R)

DESCRIPTION:
    The ssp.model function reads a list of stellar parameters (T_{eff}, logg, Mass, log[$L/L_{\odot}$]) and the corresponding synthetic stellar spectra S(λ, Mass) computed for each pair of T_{eff}, logg:

$$T_{eff,i}, \log g_i, Mass_i, L_i \rightarrow S_i(\lambda)$$

$$\vdots$$

$$T_{eff,N}, \log g_N, Mass_N, L_N \rightarrow S_N(\lambda)$$

The stellar parameters in the input file are assumed to be listed from the less massive to the most massive star (i.e., $Mass_i < Mass_{i+1}$).

The stellar population is then divided into N mass bins, as follows:

bin 1 → masses from $M_{l,1}$ = 0.08 $M_\odot$ to $M_{u,1}$ = *Mass*[L = (L_2 + L_1)/2]
bin *i* → masses from $M_{l,i}$ = *Mass*[L = (L_{i-1} + L_i)/2]
to $M_{u,i}$ = *Mass*[L = (L_i + L_{i+1})/2]
bin N → masses from $M_{l,N}$ = *Mass*[L = (L_{N-1} + L_N)/2] to $M_{u,N}$ = $Mass_N$

where *Mass*[L] correspond to the stellar mass of a star with luminosity L (interpolated from the isochrones). The isochrones are extrapolated down to 0.08 $M_\odot$.

For each mass bin, the following quantities are computed:

$M_{bin,i} = \int_{M_{l,i}}^{M_{u,i}} m \cdot \Phi(m) \cdot dm$ → total stellar mass within the mass bin *i*;

$L_{bin,i} = \int_{M_{l,i}}^{M_{u,i}} L(m) \cdot \Phi(m) \cdot dm$ → total luminosity of stars within the bin;

$L_{star,i} = L_i \cdot \int_{M_{l,i}}^{M_{u,i}} \Phi(m) \cdot dm$ → total luminosity of stars within the bin assuming that L(m) = constant = L_i

$N_i = \int_{M_{l,i}}^{M_{u,i}} \Phi(m) \cdot dm$ → number of star within the bin

$L_{corr,i} = L_{bin,i} / L_{star,i}$ → correction factor taking into account the variation of L(m) within the bin

The SSP spectrum is then computed as

$$F_{SSP}(\lambda) = \frac{\sum_{i=1}^{N} S_i(\lambda) \cdot L_{corr,i} \cdot N_i}{\sum_{i=1}^{N} M_{bin,i}}$$

$F_{SSP}(\lambda)$ units: F/($L_\odot$ $M_\odot$ Å).

IMFs:

Kroupa IMF is defined as:

$$\Phi(m) \begin{cases} \propto m^{-2.7} & , \ 1.0 \leq m < 100\ M_\odot \\ \propto m^{-2.3} & , \ 0.5 \leq m < 1.0\ M_\odot \\ \propto m^{-1.3} & , \ 0.08 \leq m < 0.5\ M_\odot \end{cases}$$

Unimodal IMF

$$\Phi(m) \propto m^{-slope}$$

Salpeter IMF = Unimodal IMF with slope = 2.3

EXAMPLES:

1. Create the SSP spectra of a population with 8 Gyr by combining the synthetic stellar spectra of 16 stars listed in the file ./Stellar_pars/stpars_fe+0.20a+0.20age08.0ms09rg08.dat, according to Kroupa IMF, with [Fe/H] = 0.2, [a/Fe] = [O, Mg, Si, Ca, Ti/Fe] = 0.2, [Na/Fe] = 0.0, in the region from 6000 to 6500 A.

   >> ssp.model(0.2, 0.2, 8, 'Kroupa', fwhm = 2.5, CaFe = 0.4, n_ms = 9, n_rg = 8, lmin = 6000, lmax = 6500)