FRANEC CODE

(Pise and Naples groups)

A complete description of all the updates of the physical inputs is not available, see:

for general informations about the structure of the code:

- Chieffi & Straniero 1989 ApJS 71, 47

for some updates of the physical inputs:

- Ciacio, Degl'Innocenti, Ricci 1997 A&AS 123, 449
- Cariulo, Degl'Innocenti, Castellani 2004 A&A 421, 1121

for the description of the physics adopted for WD models:

- Prada Moroni & Straniero 2002

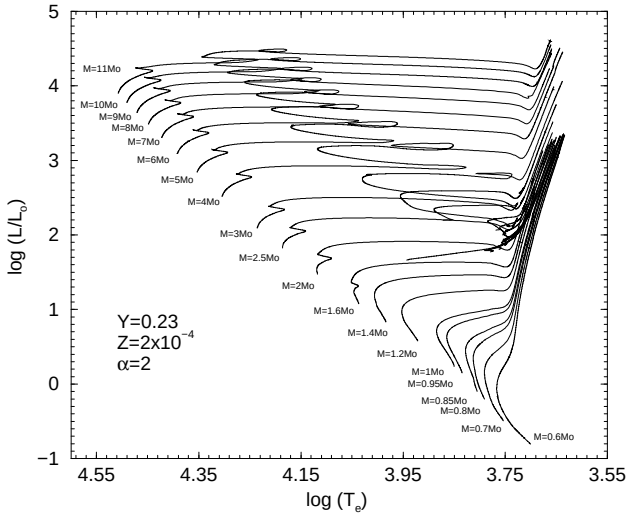
• Covered evolutionary phases: from pre-main sequence to white dwarf

• Mass range: $\approx 0.6\ M_\odot \div \approx 20\ M_\odot$

Databases of stellar models and isochrones partially available on the web at the URL:

http://astro.df.unipi.it/SAA/PEL/Z0.html

http://www.mporzio.astro.it/ marco/GIPSY/homegipsy.html



Numerics

• The integration of the four equations is performed by applying the Henyey method.

•Three zones of integration:

atmosphere: independent variable=optical depth, until τ=2/3 or to the onset of convection

sub-atmosphere: independent variable=pressure, until a defined (variable) value in mass

Interior: independent variable=mass

• Convergence of a model: percentage corrections to the quantities $\leq 2{\cdot}10^{-4}$ and equations verified at the $2{\cdot}10^{-4}$ level.

• Time steps: the quantities R, L, T, P must not vary, from one model to the next, in each mesh point more than a prefixed value, e.g. for the models of Task 1 we adopted:

δR/R=.002 δL/L=.03 δP/P=.1 δT/T=.03 δX/X=.01

$\delta L_{pp}/L_{pp}$=.01 $\delta L_{CNO}/L_{CNO}$= .01 $\delta L_{3\alpha}/L_{3\alpha}$=.01

• The models can start either from the zero age homogeneous main sequence (ZAMS) or from the chemical homogeneous quasi-static PMS model with a central temperature less then $T_c \approx 10^6$ K.

• The equations for the chemical evolution of the matter are solved by a classical Raphson-Newton method. The chemical composition is updated then the equations for the interior and the atmospheric structure are solved with the new estimated chemical composition.

• Reference values: $L_\odot = 3.846 \cdot 10^{33}$ erg/s , $M_\odot = 1.989 \cdot 10^{33}$ g , $R_\odot = 6.9599 \cdot 10^{10}$ cm G=$6.668{\cdot}10^{-8}$ dyn cm^2 g^{-2}

Numerics

Interior:

• Mass distribution of the mesh points: fixed by the requirement that the quantities R, L, P, T, M should not vary more than some pre-fixed amount from one mesh point to the next one, e.g. for the calculations of Task 1 we required:

$$\delta R/R = .07 \quad \delta L/L = .03 \quad \delta P/P = .15 \quad \delta T/T = .05 \quad \delta M/M_{tot} = .01$$

typical number of meshes $\approx 800 \div 900$

Sub-atmosphere:

Integration method: fourth-order Runge-Kutta (variable number of meshes, usually between 300 and 400)

Atmosphere:

The $T(\tau)$ relation is the scaled solar one by Krishna Swamy (1966)

The radius (R_{tot}) is obtained from: $L_{tot} = 4\pi\ R_{tot}^2 \sigma\ T_e^4$

Physical Mechanisms

Convection

- Extension: Schwarzschild criterion

- The time scale of mixing is always assumed smaller than the nuclear burning time scale and a first order Taylor expansion is used to follow the burnings in the convective regions.

- Superadiabaticity in the external layers calculated following the derivation of Cox & Giuli (1968) of the mixing lenght formalism of Bohm-Vitense

- Induced overshooting (by the conversion of He into C and O) and semiconvection included in central He burning

- Mechanical overshooting: can be included or not for central H and He burning. The extension is calculated from the border of the Schwarzschild convective region throught the parameter:

$$\alpha_{ov} = \Delta M_{ov} / H_{pm}$$

where $H_{pm} = -\ dM/d\ln P$

In the overshooting region the material is fully mixed.

- Effects of rotation not included

Energy generation

• Reaction rates: NACRE collaboration (Angulo et al. 1999)

• D (and other light elements: ^{7}Li, ^{9}Be etc..) burning in PMS is taken into account; original D abundance from Geiss & Gloeckler 1998

• During H burning the temporal evolution toward the equilibrium abundance of ^{3}He, ^{12}C, ^{14}N, ^{16}O is explicity followed. The original ^{3}He abundance is taken from Geiss & Gloeckler 1998

• Neutrino energy losses: Itoh et al. (1996)

• Screening: Salpeter (1954) for weak screening ; Graboske et al. (1973) and De Witt et al. (1973) for weak-intermediate and intermediate-strong screening. Itoh,Totsuji, Ichimaru 1977, Itoh et al. 1979 for strong screening

Equation of state

• OPAL 2001 tables for the appropriate value of Z using the OPAL interpolation program.
Linear interpolation in T and P, spline interpolation in H abundance.
For values of T and P out of the OPAL2001 grid we adopted the Prada Moroni & Straniero 2001 EOS (private communication, see also Straniero 1988)

In case of diffusion the variation of the total metallicity is not taken into account in the calculation of the EOS

Opacity

- LogT $\geq$ 4.2

OPAL opacity tables with G&N93, G&S98 or Asplund et al. 2005 mixture (calculated by adopting the facilities at the URL:http://www-phys.llnl.gov/Research/OPAL/)

- LogT $<$ 4.2

Opacity tables from Alexander & Ferguson (1994).

Spline interpolation in Z, cubic interpolation in temperature and density, linear interpolation in H abundance.

A mass-weighted combinations of He, C and O is adopted in the H exausted regions

In case of diffusion the variation of the total metallicity is taken into account

- Conductive opacity: Potekhin (1999) or Itoh et al. (1983)

Atomic diffusion

(can be included or not)

Diffusion coefficients by Thoul et al. (1994)

Radiative acceleration not included