Toulouse-Geneva Evolution Code

M. Castro

Laboratoire d'Astrophysique de Toulouse-Tarbes
Observatoire Midi-Pyrénées
Université Paul Sabatier – Toulouse III

Physical Inputs (1)

- **Equation of state** : MHD 80-85, 92; OPAL 96

  OPAL 2001 tables, for the appropriate value of Z (Z=0, 0.02, 0.04).

  quadratic interpolation at fixed temperature at three values of density, followed by quadratic interpolation along temperature

  results are smoothed by mixing overlapping quadratics

- **Opacity** : OPAL 92, 93, 95; Los Alamos

  OPAL 1996 tables, with Alexander low-temperature values

Physical Inputs (2)

- **Nuclear reactions** : Caughlan & Fowler 88; Adelberger et al. 98

  NACRE tables

  calculation of the nuclear reactions rates

  calculation of the nuclear and gravitational energy production rates

  calculation of screening corrections

- **Convection treatment** : mixing-length theory

  the mixing-length parameter α is a *free parameter*

  convection zones limits are determined by Ledoux criterion

Physical Inputs (3)

- **Chemical composition** : Grevesse&Noels 93

  chemical elements are separately treated until Mg

  the initial helium composition Y_0 is a *free parameter*

  Asplund 04 composition is available

- **Metallicity** : overall metallicity of the star

How the code works ?

- Reading of the physical inputs
- Calculation of the **initial chemical composition** with respect to inputs Y_0 and Z, and of Grevesse&Noels 93 composition
- Calculation of an initial polytropic model
  PMS (n=1.5) or MS (n=3)
- Reading of the previous model
  calculation of the age (previous age + time step)
  calculation of L and T_{eff} by extrapolation of previous L and T_{eff}
  Henyey method for computation of the stellar structure at each step of the evolution

Henyey method

- Spherical symmetry in hydrostatic equilibrium
- The star is considered to be divided into **concentric shells**

  → 1D system in which radius is divided into zones by a set of mesh points
- All quantities are evaluated at the same mesh points
- At each mesh points : 4 unknown variables r, P, T, l

  ($r=y_1$, $P=y_2$, $T=y_3$, $l=y_4$)

  K mesh points → (4K-2) unknown variables (r = l = 0 at the centre) which have to fulfil (4K-2) equations

- 4 equations for the innermost interval between central point $m^K=0$ and m^{K-1}

  $C_i(r^{K-1},P^{K-1},T^{K-1},l^{K-1},P^K=P_C,T^K=T_C)=0$; i=1,4

- 4(K-2) equations for the K-2 shells of the interior

$$A_i^j=\frac{y_i^j-y_i^{j+1}}{m^j-m^{j+1}}-f_i(y_1^{j+1/2},\ldots,y_4^{j+1/2})=0\ ;\ i=1,4$$

- 2 equations for the outer boundary condition : $P = \pi$ (R,L) and $T = \theta$ (R,L)

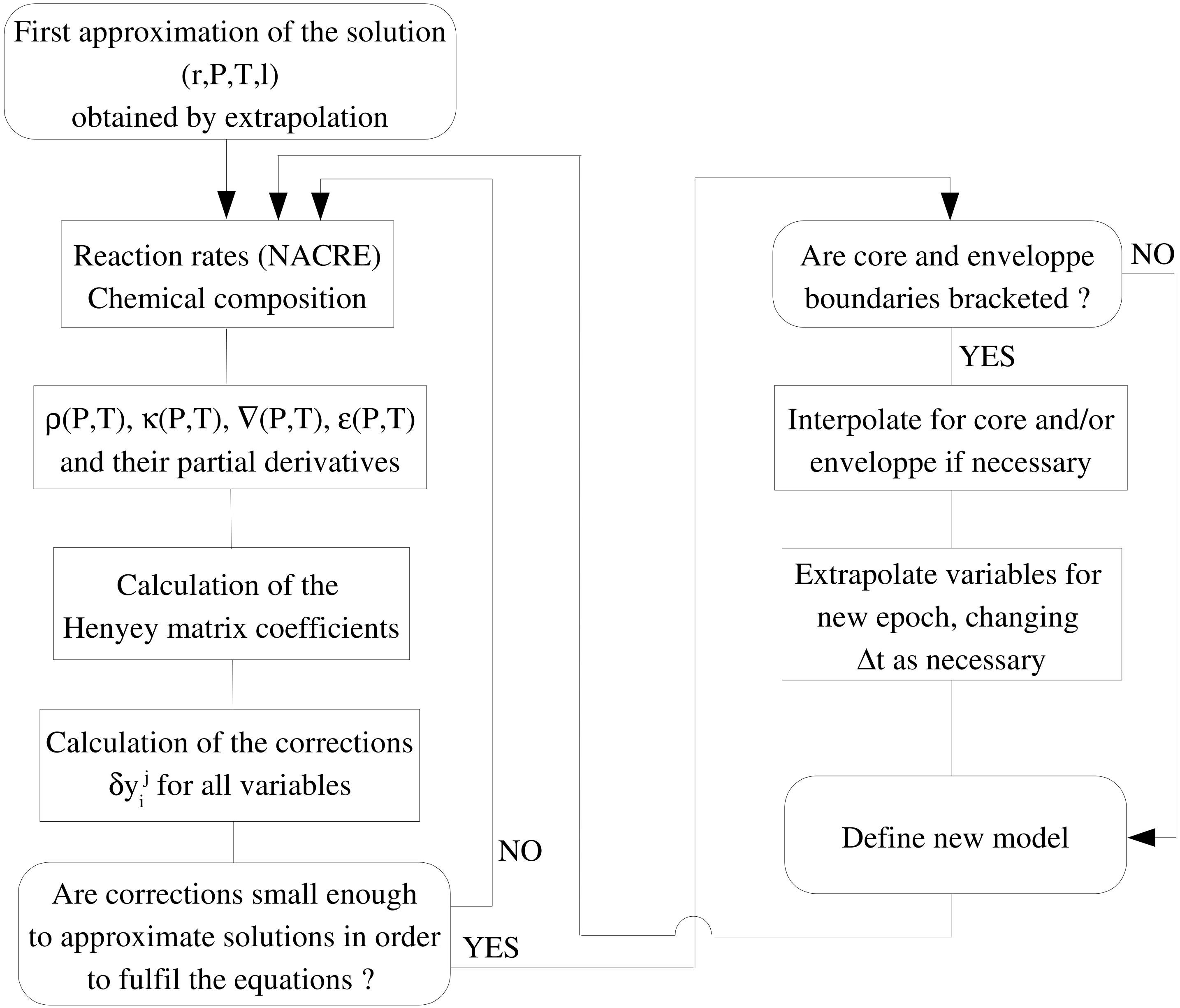
$$B_1=y_2^1-\pi(y_1^1,y_4^1)=0\ ,\ \ B_2=y_3^1-\theta(y_1^1,y_4^1)=0$$

- Calculation by **iteration** :

  first approximation $(y_i^j)_1$ of the solution obtained by extrapolation of a previous solution

  corrections for all variables such as : $(y_i^j)_2=(y_i^j)_1+\delta y_i^j$

  Henyey matrix composed by the derivatives of the equations with respect to the y_i^j



Henyey et al., 1964

Non-standard processes

- **Microscopic diffusion : gravitational settling and thermal diffusion** (Chapman & Cowling 70, Paquette 86)
- **Different kinds of mixing :**

  Zahn 92 : turbulent mixing

  Richard 96 : μ-gradient cutoff

  Théado 2003 : meridional circulation
- **Overshooting** : temporary extension of the mixing of the convective zone
- **Radiative forces in progress**