CESAM 2k in brief

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Now (re)written in Fortran 90/95 : CESAM2k

Only 14 files to compile in order to make the executable,
This code need only to be compiled once,
Easier to implement some new (physical) option (generic routines).

Available in two versions :

- **V1.0 for the (recommended, official) version (as discussed in this workshop ?)**
- V1.14 for the (current, unstable) version (for evaluation only) [2005-09-20]
- also available, historic versions (cesam4, cesam5 : not recommended)

With manuals (a concise one of 80 pages, a full one of 280 pages) [in French]

Work in progress (since 2005) : rotation (with the formalism Maeder-Zahn) with diffusion of angular momentum *(not yet publicly available)*

Some (technical) points

Modularized for all ‘physical’ (with the use of ‘generic’ routine), ‘numerical’ routines

Implicit pseudo-spectral method with B-splines (order may be changed),
Quasi-static equilibrium by collocation method,
Implicit method to solve the stiff problem of chemical composition evolution :
may be computed without diffusion (Lobatto-3C) or with diffusion (Galerkin)

➔ CESAM is (actua1ly) 1D stellar structure code
➔ CESAM is also a stellar evolution code !

Some changes of variables to suppress singularities at origin,
An adaptative grid for integration (in radial coordinates) allows, for example, the localization of convective zones on a mesh point, …

The different options (actually) available with this version of Cesam2k and how to use them

I detail, here, the unique required configuration file called "*.don*" (new version mid-2005) used in this (public, current and official) version of Cesam2k.

In '**[*x*]**', it is indicated whether the corresponding (input) parameters may have some impact in the (accuracy) of the results. Therefore, this parameter must be checked (in detail) for comparison purposes !!!!

Note that more **[*x*]** is higher, more the (output) results may be sensitive to the choice or the value of the corresponding (input) parameters.

For instance, rating of **[0]** (or **[1]**) means that the sensitivity is weak or it is very easy to check the differences (it is the case of physical constants).

CESAM main parameters

```
&NL_CESAM
NOM_CHEMIN = '~/CESAM/DATA/',
NOM_CTES   = 'ctes_94'      ,
NOM_DES    = 'no_des'       ,
NOM_OUTPUT = 'no_output'    ,

N_MAX      = 2000           ,
PRECISION  = 'rg'
/
```

← depends on your own local installation

← the fundamental physical constants used **[0]**

← how Cesam produces graphics during run (*)

← how Cesam generates data for post-processing like oscillations computation

← maximum number of (internal) shells **[1]**

← **the control of overall accuracy (**)** **[5]**

(*) Cesam uses PGPLOT graphics library (DISLIN may be envisaged if manpower available)

(**) there are predefined sets of accuracy parameters such as : `'np'` (normal precision),
`'pr'` (realistic precision),
`'sp'` (super precision),

Here, `'rg'` allows the user to modify/choose individually these parameters (29 in all !)
For example, the time step is controlled by 9 parameters.

Rmk: 'chemin' in French is 'path' in English
Rmk: 'nom' in French is 'name' in English

Mass parameters

```
&NL_MASS
MTOT       = 1.05d0        ,
NOM_PERTM  = 'pertm_ext'   ,
MDOT       = 0.d0
/
```

← (initial) mass of the star (*)
← 2 main options for mass loss (**)
← Here, mass is constant !

(*) In Cesam (`'ctes_94'`), M_{sun} is defined as 1.98919d33 and, from the product G x M_{sun} (which is a very well known quantity : 1.32712438d26), we determine ***a*** value of G (the constant in physics whose the accuracy is the worst determined) : Hence G = 6.6717d-8 (to be compared with the most recent value given by Codata : (6.673+/-0.010)d-8) **[1]**

Rmks : In `'ctes_85'` , G = 6.67259d-8 , M_{sun} = 1.9891d33
We can also discuss about the values of R_{sun}, L_{sun} .!!!

(**) `'pertm_ext'` for a linear mass loss over time
`'pertm_waldron'` for the empirical mass loss of Waldron

Rmk: 'pert(e)' in French is 'mass loss' in English

Evolution control parameters

```
&NL_EVOL
AGEMAX           = 500.d0 ,     ← In Myr  (*)
ARRET            = 'else' ,     ← How to stop the run (**)
                                          many possibilities : see following fields
DTLIST           = 1.d10  ,     ← used only to produce detailed models
LOG_TEFF         = 10.d0  ,     ← used to stop with a 'Teff' condition
NB_MAX_MODELES = 2000   ,       ← Maximum number of models during the run
HE_CORE          = -1.D0  ,     ← used to stop with a mass of He core condition
T_STOP           = 5.d7   ,     ← used to stop with a central temperature condition
X_STOP           = -0.1d0       ← used to stop with a central X (H) condition
/
```

Here, Cesam2k stops when (`NB_MAX_MODELES >= 2000 .OR. TEMP_C >= 50 MK`)

(*) In Cesam2k, for `'ctes_85'` , 1 yr = 365.24219878 d = 31 556 925.9747 s
but, now, for `'ctes_94'` , 1 yr = 365.25 d = 31 557 600 s
difference of 674.0.25 s ($2\ 10^{-5}$) **[0]**

(**) Cesam can, also, stop automatically at `'zams'` , tams (`'post'`), `'cohe'` or `'coca'`

Rmk: 'arret' in French is 'stop' in English

Chemical composition parameters

```
&NL_CHIM
GRILLE_FIXE = .False.        ,   ← .False. suggested [1]
NOM_ABON    = 'solaire_gn'   ,   ← Basis for initial chemical composition mixture
MODIF_CHIM  = .False.        ,   ← Does allow it to be modified or not ?
GARDE_XISH  = .False.        ,   ← And, in this case, keeping the Xi/H ratios
X0          = 0.00d0         ,   ← In other cases, initial value of X (H)
Y0          = 0.270d0        ,   ← In all cases, initial value of Y (He)
ZSX0        = 0.0245d0           ← In other cases, initial value of Z/X ratio
/
```

Of course, for comparisons, the same (initial) composition must be used (to check) ! **[4]**
Here, there is typical values for a solar model (and `X0` is computed from `Y0` and `ZSX0`).

For more details how to use these options and how they interact (not so trivial), see the documentation.
To date, there is 7 predefined chemical mixtures plus the possibility to create its own modified mixture.

Rmk: 'grille' in French is 'grid' in English
Rmk: 'nom' in French is 'name' in English
Rmk: 'garde' in French is 'keep' in English

Convection control parameters

```
&NL_CONV
NOM_CONV = 'conv_cm' ,  ← Which convection routines do you want ?  (*)
ALPHA    = 1.00d0    ,  ← The α parameter for MLT,
OVSHTS   = 0.0d0     ,  ← For upper overshoot
OVSHTI   = 0.0d0     ,  ← For lower overshoot
JPZ      = .False.   ,  ← Do you want convective penetration (JPZ prescription) ?
CPTURB   = 0.d0      ,  ← Coefficient of turbulent pressure
LEDOUX   = .False.      ← .False. suggested
/
```

(*) To date, there is 5 predefined routines to compute convection.
Here, we use Canuto - Mazitelli convection routine (with no overshoot).

For comparison purpose, check how physics is implemented between various programs. **[2]**

Rmk: 'nom' in French is 'name' in English

Diffusion control parameters

```
&NL_DIFF
DIFFUSION = .False.      ,  ← Do you want chemical evolution with diffusion ?
NOM_DIFFM = 'diffm_mp'   ,  ← Which microscopic diffusion routines used ?  (*)
NOM_DIFFT = 'difft_nu'   ,  ← Which turbulent diffusion routines used ?  (**)
D_TURB    = 0.00E+00     ,  ← Coefficient of isotropic turbulent diffusion
RE_NU     = 1.000        ,  ← Coefficient of radiative diffusivity
NOM_FRAD  = 'no_frad'       ← Which routines for radiative acceleration ?  (***)
/
```

(*) To date, 3 routines : `'diffm_mp'`, `'diffm_br'` and `'diffm_0'` .

(**) To date, only 1 routine ! (need the two following coefficients).

(***) To date, only `'no_frad'` is publicly available.

The use of microscopic diffusion increases the computational time by a factor from 10 to 50 .

Rmk: 'nom' in French is 'name' in English

Rotation control parameters

```
&NL_ROT
ROT_SOLID = .True.       ,
W_ROT     =  0.d0        ,
UNIT      = 'kms/s'      ,
W_FORM    = 0.d0         ,
NOM_DIFFW = 'diffw_mpz'  ,
NOM_PERTW = 'pertw_0'    ,
P_PERTW   = 0.d0         ,
PW_EXTEND = 0.d0
/
```

← At this time, use only this value.

← Angular or equatorial velocity or period

← May be `'kms/s'`, `'rad/s'` or `'jours'`

} Options for angular momentum diffusion

‘`W`’ means ‘omega’ (ω)

This is under development by Pierre Morel and is not yet available.

Rmk: ‘jours’ in French is ‘days’ in English

EOS control parameters

```
&NL_ETAT
NOM_ETAT = 'etat_eff'                    ,  ← The name of the routine.  (*)
F_EOS    = 'eos_opal_195.bin',7*' '      ← And, if any, its associated files.
/
```

(*) To date, there is some EOS routines, among them : `'etat_eff'` , `'etat_ceff'` , `'etat_mhd'` or different versions of `'etat_opal'` .

Opacity control parameters

```
&NL_OPA
NOM_OPA = 'opa_yveline_lisse'        ,  ← The name of the routine.  (*)
F_OPA   = 'opa_yveline.bin',7*' '       ← And, if any, its associated files.
/
```

(*) To date, there is some opacity routines, among them : `'opa_yveline'` , `'opa_yveline_lisse'` , `'opa_houdek'` or different versions of 'opal' opacities e.g. `'opa_int_zsx'` , `'opa_opal2'` ….

Rmk: 'nom' in French is 'name' in English
Rmk: 'etat' in French is 'state' in English
Rmk: 'lisse' in French is 'smooth' in English

Nuclear reaction and network control parameters

```
&NL_NUC
NOM_NUC      = 'ppcno9' ,        ← The name of the routine.  (*)
NOM_NUC_CPL  = 'NACRE'  ,        ← And, if available, which compilation ?  (**)
MITLER       = .False.
/
```

(*) The routine implements the (thermo)nuclear reaction network to be used during the stellar evolution. Cesam2k contains already the whole (nuclear) data for the most common nuclides and reactions. There is, for now (2005-09-22), **14** available networks.

(**) For comparison purpose, it may be important to know how a nuclear reaction rate is used from a given compilation. For example, the NACRE compilation gives reaction rates as tables or as (fitting) analytic formulae. In the case of direct use of tables, the Hermitian interpolation is (probably) the best suitable case. Even in the case of analytic formulae, there are some ways to use the formula : directly to compute, when necessary (shell by shell, when temperature is known), the requested reaction rate OR (the case in Cesam2k) to use it to compute spline - coefficients of the corresponding reaction rate and, after, using only splines to compute the necessary rate.

[3]

Rmk: 'nom' in French is 'name' in English

Atmosphere control parameters

```
&NL_ATM
NOM_ATM     = 'lim_atm' ,   ← The best choice for atmosphere restitution
NOM_TDETAU  = 'hopf'    ,   ← And the corresponding T(τ) law.  (*)
TAU_MAX     = 10.d0     ,   ← Optical depth of the matching point  [2]
LIM_RO      = .True.        ← Boundary conditions upon density
/
```

(*) To date, there some T(τ) routines, 2 of them (`'edding'` and `'hopf'`) are totally radiative, the others are partially radiative based of Kurucz's atmosphere models (for example, `'rogerXX'` available for different metallicities).

Note that Cesam2k computes the stellar radius as the bolometric one : $T(R_*) = T_{eff}$

Rmk: 'nom' in French is 'name' in English

NOT the end

some illustrations will be given by (at least) two other talks :

see (and listen) : Yveline, Juan, Josefina, ...