

Model comparison: CESAM – CLES

Application to Task 1.5

Josefina Montalbán¹, Yveline Lebreton², Richard Scuflaire¹ & Andrea Miglio¹

¹Institut d'Astrophysique et de Géophysique de l'Université de Liège, Belgium

²Observatoire de Paris – Meudon, France

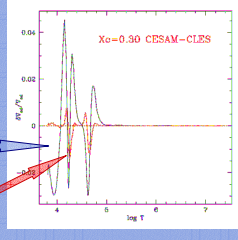
We analyse the differences between two stellar evolution codes: CESAM (OCA, P. Morel, 1997) and CLES (Université de Liège, R. Scuflaire). Both codes use the same physical inputs such as Equation of State (EoS), opacity tables, $T(\tau)$ law in the stellar atmosphere (Eddington's law), nuclear reaction rates, solar mixture (GN93) and convective transport theory (Mixing length theory).

We study the effect on the stellar structure of different numerical implementations of the same physics. In poster 2, we analyse how these small differences are reflected on the oscillation frequencies.

Equation of State : OPAL 2001

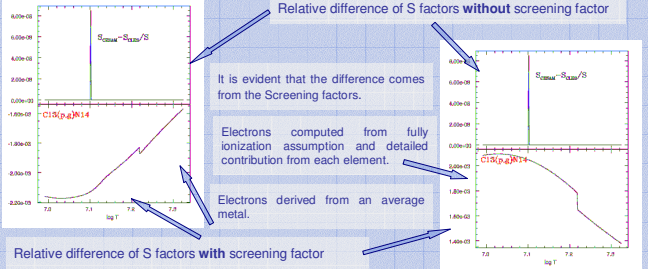
CESAM directly use the thermodynamic variables from OPAL tables. CLES derives Γ_1 , Γ_3^{-1} , and C_p from P, χ, χ_r and C_v given in OPAL and by using the thermodynamics relations (CLES-Cv). Furthermore CLES does not use the interpolation routine given by OPAL. The intrinsic difference computed for the internal structure of a $X_c=0.30$ model, is given by the **BLUE** line.

A EoS computed by using CESAM directly use the thermodynamic variables from OPAL tables. CLES derives Cv Γ_3^{-1} , and C_p from P, χ, χ_r and (CLES- Γ_1). Intrinsic difference between CESAM and CLES- Γ_1 , is given by **RED** line.



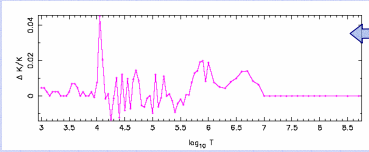
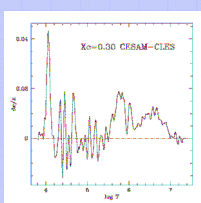
Nuclear reaction rates: NACRE

- We consider pp-chain and CNO cycle until $^{17}\text{O}(p,\alpha)^{18}\text{F}$.
- We adopt the same energy release in both codes
- weak screening factor from Salpeter (1954)
- Except for $^7\text{Be}(e,\nu)^7\text{Li}$ and $^7\text{Li}(p,\alpha)^4\text{He}$, the relative differences for the factor S span from 3.10^{-4} in pp-chain to 2.10^{-4} for CNO cycle.



Opacity

Opal 1996 for $T > 10000\text{K}$ and Alexander & Ferguson 1994 (AF) in the external layers. We compute the intrinsic differences between CESAM and CLES by comparing the opacities for a given structure (ρ, T, Z, X). The pick at $\log T=4$ comes from different schema to match Opal and AF tables.

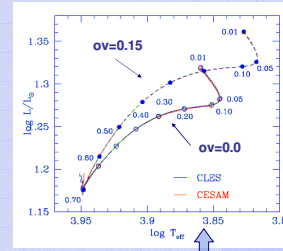
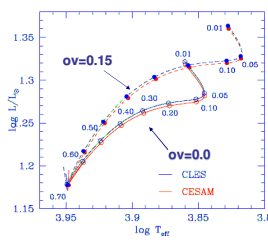


The differences do not come from the interpolation routine. This is confirmed by comparing directly the opacity tables for the same table points

Stellar Model specifications:

Mass: $2M_{\odot}$, Chemical composition $Z=0.02$, $X=0.72$. Mixing-length theory of convection (Bohm-Vitense 1958 + Heyney et al 1965) with $\alpha=1.6$. Convective overshooting $ov=0.0$ and $ov=0.15$, with adiabatic temperature gradient in overshoot region. Different evolutionary stages with central hydrogen content $X_c=0.70, 0.60, 0.50, 0.40, 0.30, 0.20, 0.10, 0.05$ and 0.01 are considered.

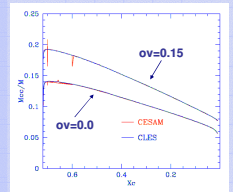
HR Diagram



CLES evolutionary tracks obtained by increasing the opacity by 0.5%

Convective core:

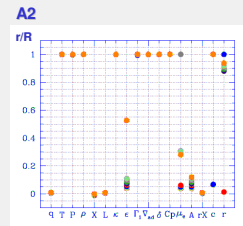
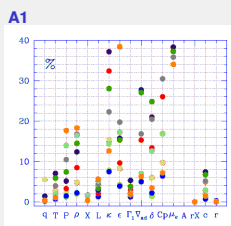
$\Delta(m_{cc}/M) \sim 5 \cdot 10^{-4}$



Stellar Structure Differences:

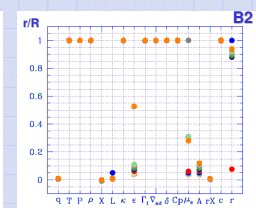
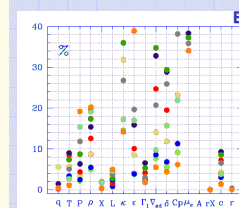
- For each X_c - model we compute the differences at a given mass, for the mass fraction (q), Temperature (T), Pressure (P), density (ρ), H mass fraction (X), Luminosity (L), opacity (κ), nuclear energy (ϵ) adiabatic exponent (Γ_1), adiabatic gradient (∇_{ad}), compressibility (δ), electron molecular weight (μ_e), Brunt-Väisälä frequency (A), sound speed (c) and radius (r).

- $X_c=0.70$
- $X_c=0.60$
- $X_c=0.50$
- $X_c=0.40$
- $X_c=0.30$
- $X_c=0.20$
- $X_c=0.10$
- $X_c=0.05$
- $X_c=0.01$



Maximum differences between CESAM and CLES: **A1** (without overshoot), **B1** (with overshoot=0.15 Hp)

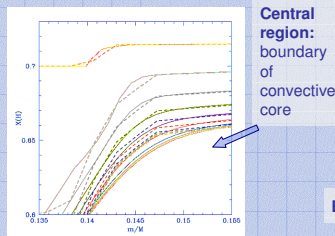
Location in r/R where the difference is maximum. **A2** and **B2**



$$\delta x = f(X_{cesam} - X_{cles})\delta(r/R)$$

$$\delta x^2 = f(X_{cesam} - X_{cles})^2\delta(r/R)$$

Overshoot = 0.0: dashed lines correspond to CLES models and continuous lines to CESAM models:

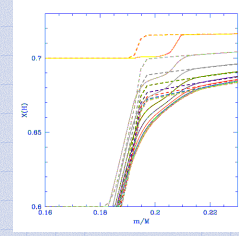


Central region: boundary of convective core

External layers. Cles stops at $\tau=2/3$

Central region: boundary of convective core

Overshoot = 0.15 and adiabatic gradient. Dashed lines correspond to CLES models and continuous lines to CESAM models



External layers. Cles stops at $\tau=2/3$