Model comparison: CESAM – CLES

Application to Task 1.5

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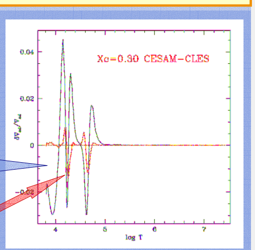
We analyse the differences between two stellar evolution codes: CESAM (OCA, P. Morel,1997) and CLES (Universite de Liege, R. Scuflaire). Both codes use the same physical inputs such as Equation of State (EoS), opacity tables, T(τ) law in the stellar atmosphere (Eddington's law), nuclear reaction rates, 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

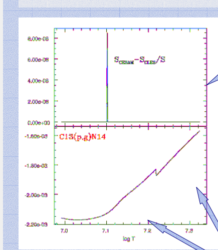
CESAM directly use the thermodynamic variables from OPAL tables.
CLES derives Γ_1, Γ_3-1, and Cp from P,$\chi\rho$, χT and Cv given in OPAL and by using the thermodynamics relations (CLES-Cv)
Furthermore CLES does not use the interpolation routine given by OPAL.
The intrinsic difference computed for the internal structure of a Xc=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 Cp from P,χ_ρ, χ_T 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 $^{17}O(p,\alpha)^{15}N$.
- We adopt the same energy release in both codes
- weak screening factor from Salpeter (1954)
- Except for $^7Be(e,\nu)^7Li$ and $^7Li(p,\alpha)^4He$, the relative differences for the factor S span from **3.10^{-4}** in pp-chain to **2.10^{-3}** for CNO cycle.



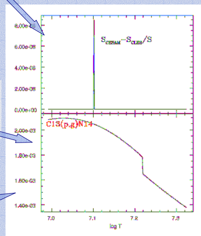
Relative difference of S factors **without** screening factor

It is evident that the difference comes from the Screening factors.

Electrons computed from fully ionization assumption and detailed contribution from each element.

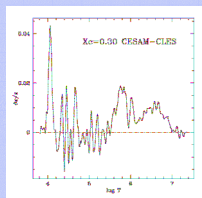
Electrons derived from an average metal.

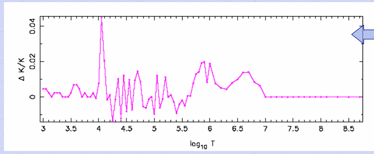
Relative difference of S factors **with** screening factor



Opacity

Opal 1996 for T> 10000K 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.



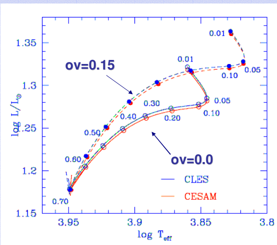


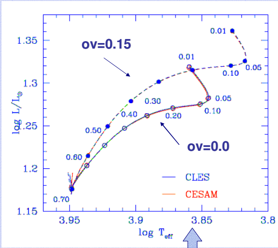
The differences do not come from the interpolation routine. That is confirmed by comparing directly the opacity tables for the same table points

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 **α=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 **Xc=0.70, 0.60, 0.50, 0.40, 0.30, 0.20, 0.10, 0.05 and 0.01** are considered.

HR Diagram

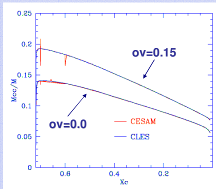




CLES evolutionary tracks obtained by increasing the opacity by **0.5%**

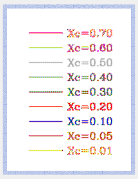
Convective core:

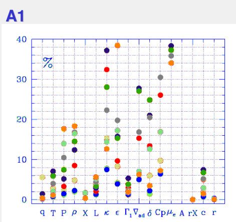
$\Delta(m_{cc}/M)\sim 5\ 10^{-4}$

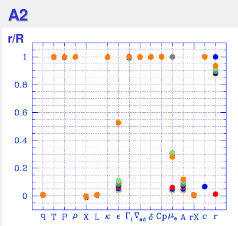


Stellar Structure Differences:

- For each Xc - 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 (Γ1), adiabatic gradient (∇_{ad}), compressibility (δ), electron molecular weight (μ_e), Brunt-Väisälä frequency (A), sound speed (c) and radius (r).

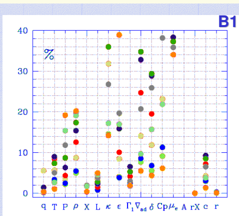


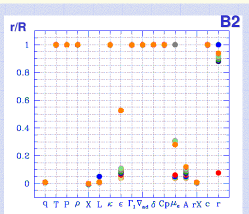


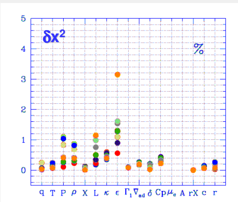


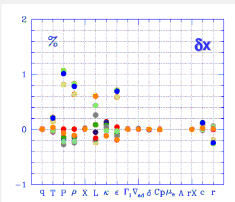
Maximum differences between CESAM and CLES: **A1** (without overshoot) , **B1** (with overshoot=0.15 Hp)

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



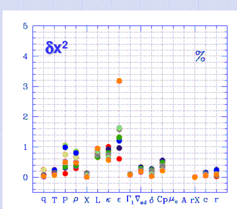


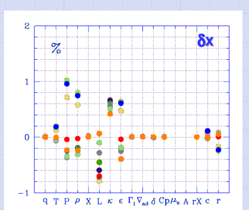




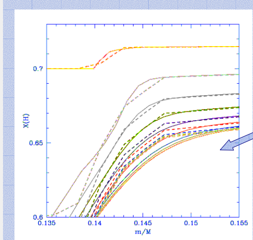
$$\delta x = \int (X_{\mathrm{cesam}} - X_{\mathrm{cles}})\delta(r/R)$$

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

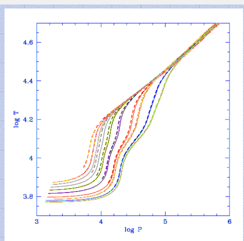




Overshoot = 0.0: dashed lines correspond to CLES models and continuous lines to CESAM models:

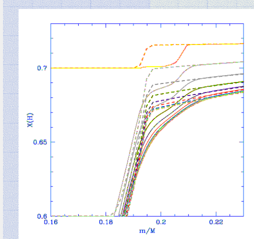


Central region: boundary of convective core

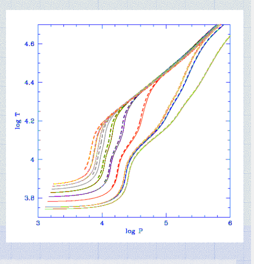


External layers. Cles stops at τ=2/3

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 τ=2/3