Summary of Aarhus workshop

24 – 28 October 2005

Jørgen Christensen-Dalsgaard

Issues

- Numerical accuracy
- Physical consistency
- Model differences
- Near-surface effects
- Semiconvection

Intrinsic numerical accuracy

- Compare models computed with a given code and given parameters
- Vary number of meshpoints
- Vary number of timesteps

Case 1.1

0.9 M–, X_c = 0.35

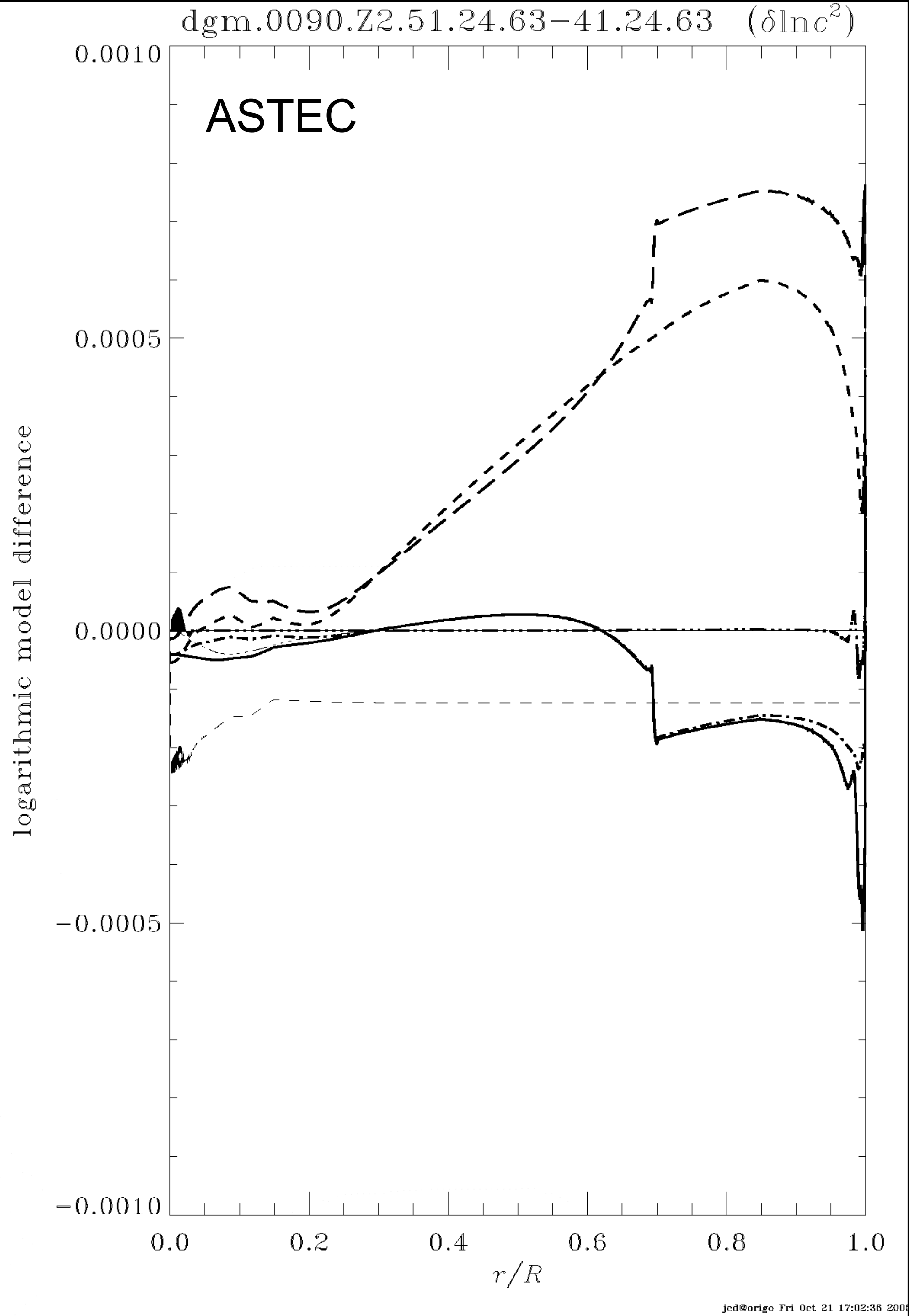
^{3}He in equilibrium

Test effect of no. of meshpoints:

(N = 1200) – (N = 600)

Line styles:

- - · - · - · - · - : $\delta\ln T$
- - - - - - - - - : $\delta\ln p$
— — — — : $\delta\ln\rho$
———— : $\delta\ln c^2$
- · · · — · · · : $\delta\ln\Gamma_1$
———— : $\delta\ln q$
- - - - - - - - : $\delta\ln L$
— · · · — · · · : δX



Case 1.1

0.9 M⊙, X_c = 0.35

^{3}He in equilibrium

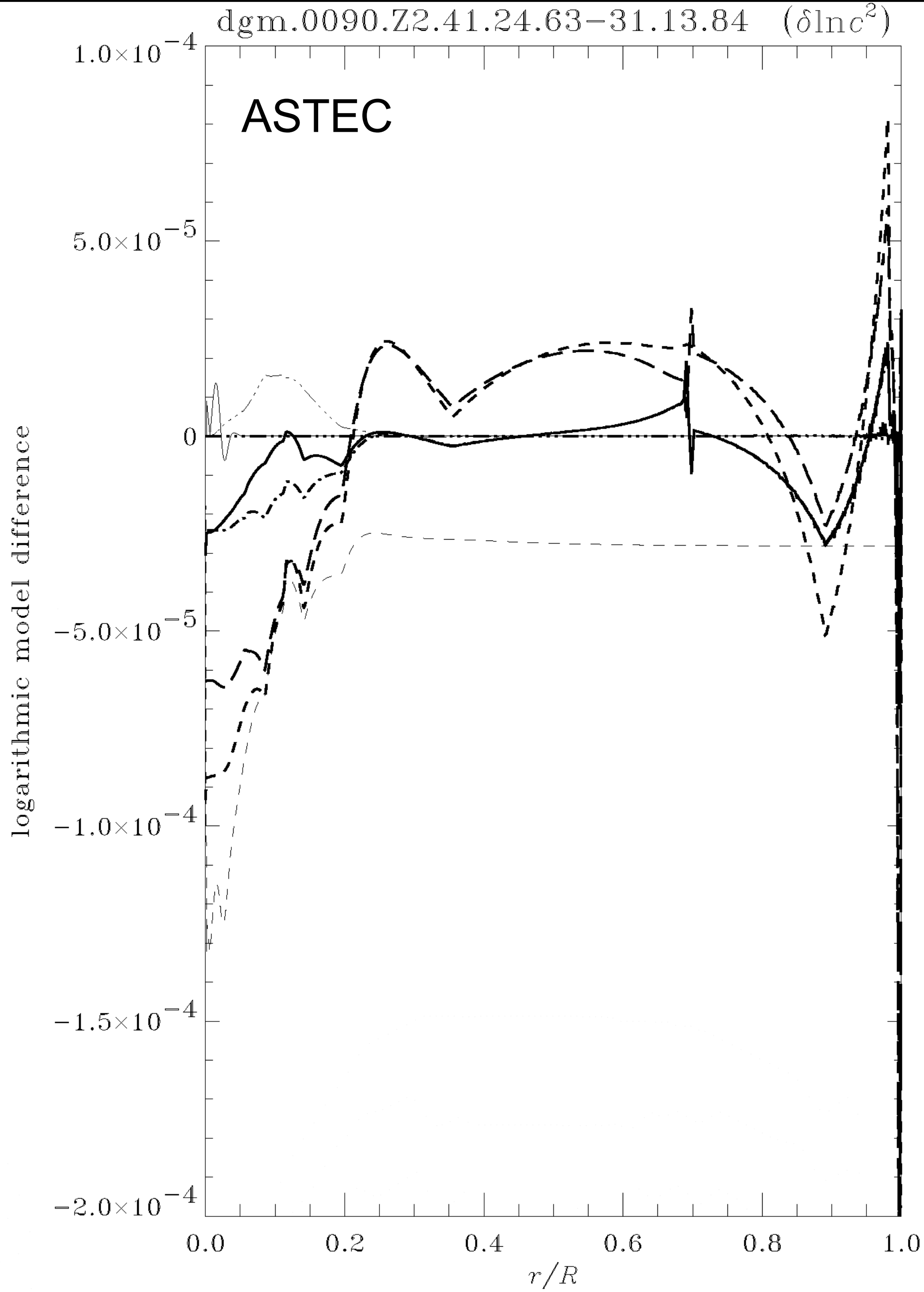
Test effect of no. timesteps:

(N_t = 24) – (N_t = 13)

($\Delta\ y_{max}$ = 0.025) - ($\Delta\ y_{max}$ = 0.05)

Line styles:

- : $\delta \ln T$
- : $\delta \ln p$
- : $\delta \ln \rho$
- : $\delta \ln c^2$
- : $\delta \ln \Gamma_1$
- : $\delta \ln q$
- : $\delta \ln L$
- : δX



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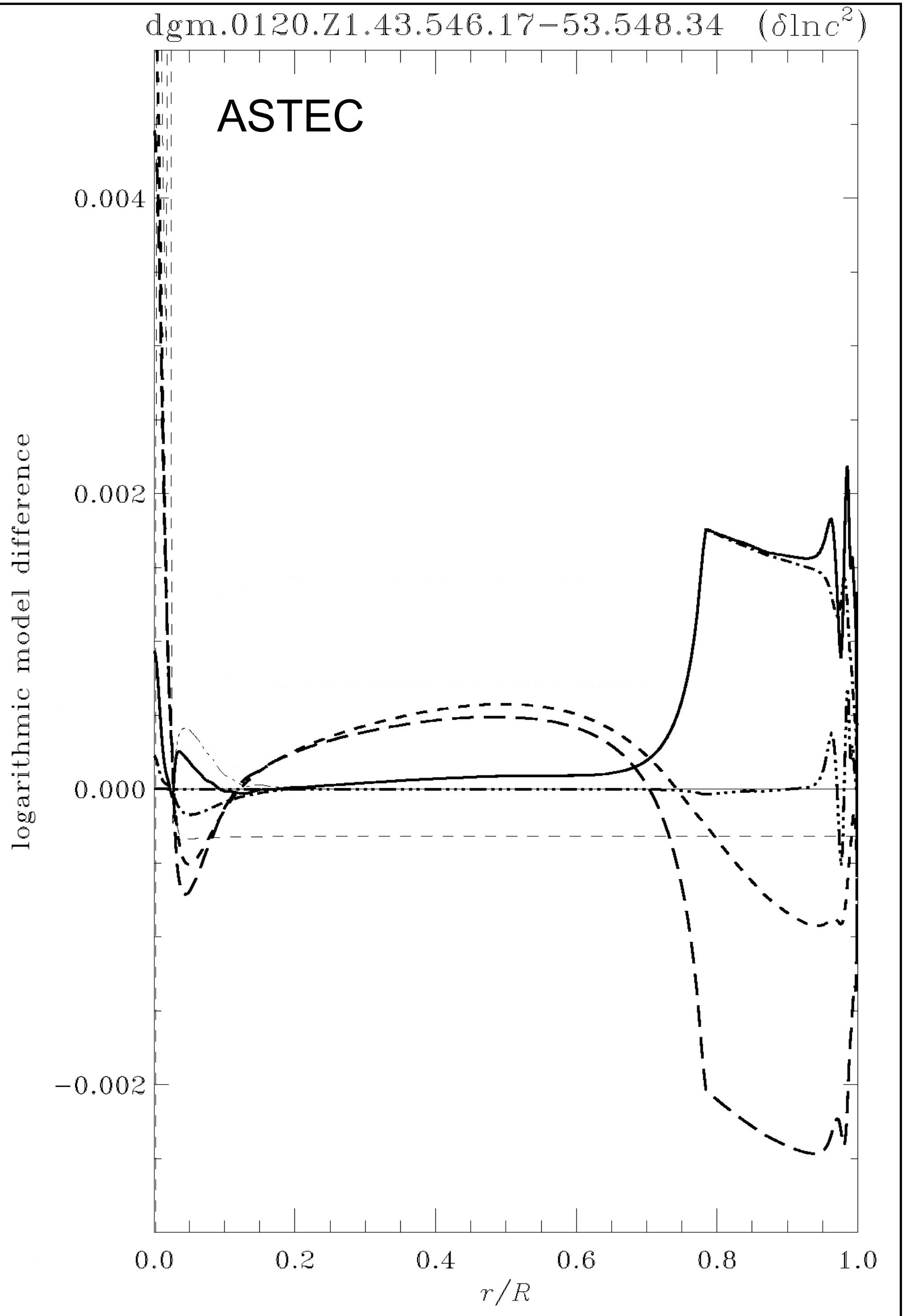
Case 1.3

1.2 M–, M_c = 0.1 M–

^{3}He in equilibrium

Test effect of no. of meshpoints:

(N = 600) – (N = 1200)



Line styles:

- dash-dot : $\delta \ln T$
- short dash : $\delta \ln p$
- long dash : $\delta \ln \rho$
- solid : $\delta \ln c^2$
- dash-dot-dot-dot : $\delta \ln \Gamma_1$
- thin solid : $\delta \ln q$
- thin dash : $\delta \ln L$
- thin dash-dot-dot-dot : δX

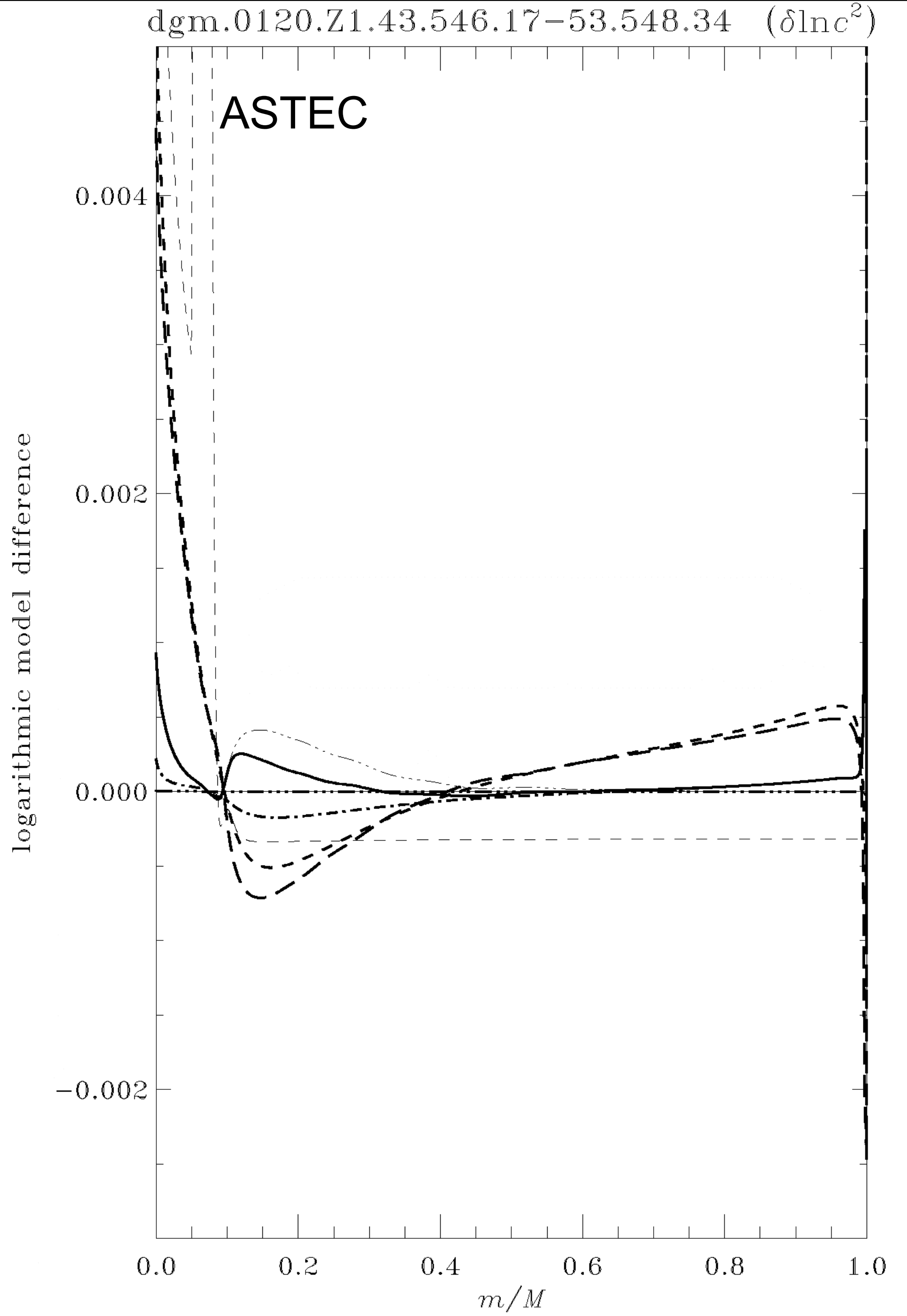
Case 1.3

1.2 M–, M_c = 0.1 M–

[3]He in equilibrium

Test effect of no. of meshpoints:

(N = 600) – (N = 1200)



Line styles:

- dash-dot line : $\delta \ln T$
- short dashes : $\delta \ln p$
- long dashes : $\delta \ln \rho$
- solid line : $\delta \ln c^2$
- dash-dot-dot line : $\delta \ln \Gamma_1$
- thin solid line : $\delta \ln q$
- thin dashes : $\delta \ln L$
- thin dash-dot-dot line : δX

Case 1.3

1.2 M–, M_c = 0.1 M–

^{3}He in equilibrium

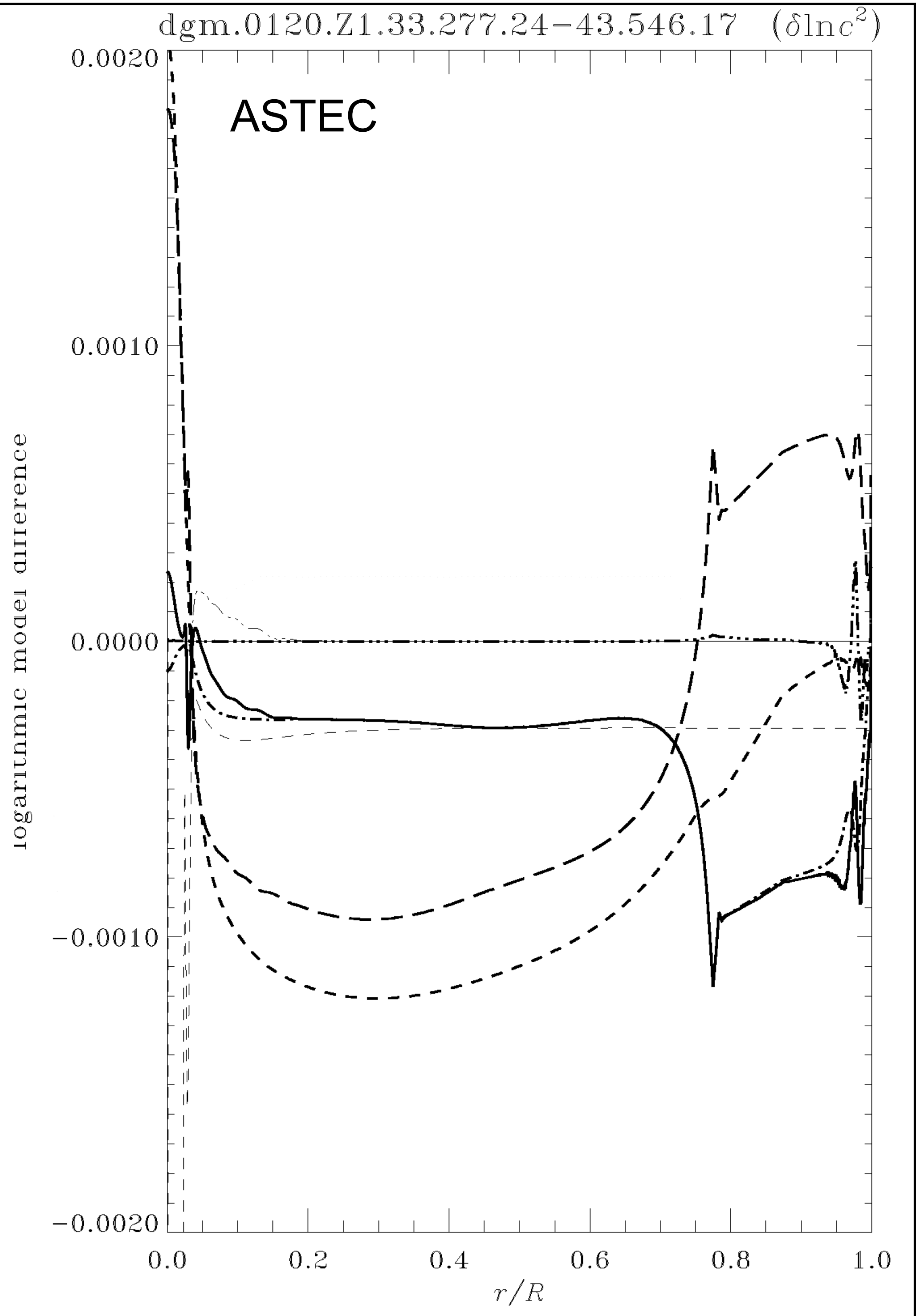
Test effect of no. timesteps:

(N_t = 277) – (N_t = 546)

($\Delta\, y_{max}$ = 0.05) - ($\Delta\, y_{max}$ = 0.025)

Line styles:

- dash-dot : $\delta \ln T$
- short dash : $\delta \ln p$
- long dash : $\delta \ln \rho$
- solid : $\delta \ln c^2$
- dash-dot-dot : $\delta \ln \Gamma_1$
- thin solid : $\delta \ln q$
- thin dash : $\delta \ln L$
- thin dash-dot-dot : δX



Case 1.5

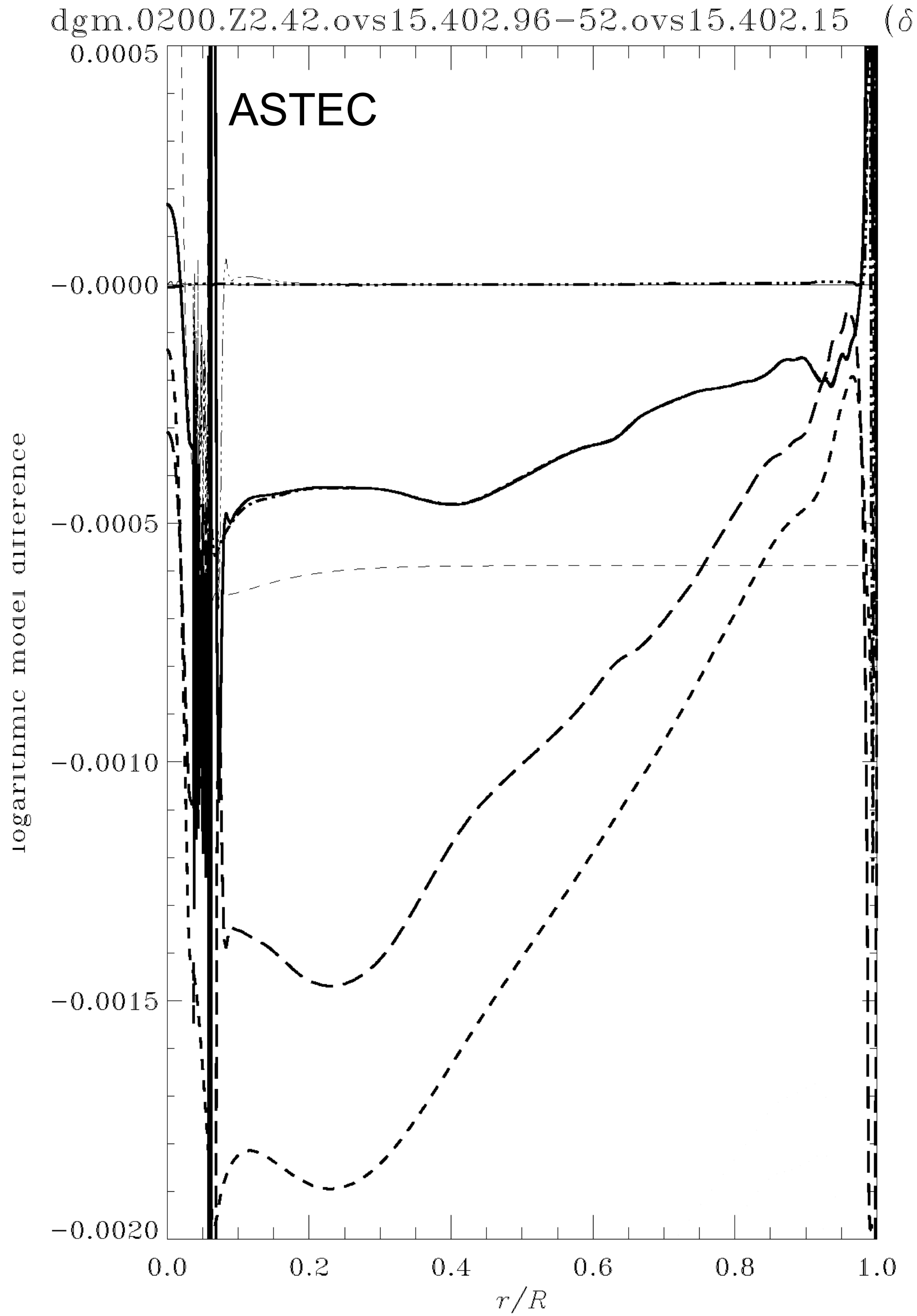
2.0 $M_\odot$, $X_c = 0.01$,

Overshoot 0.15 H_p

^{3}He in equilibrium

Test effect of no. of meshpoints:

(N = 600) – (N = 1200)



Case 1.5

2.0 M–, X_c = 0.01,

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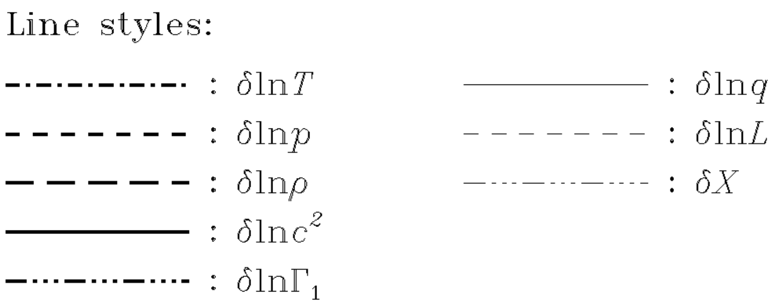
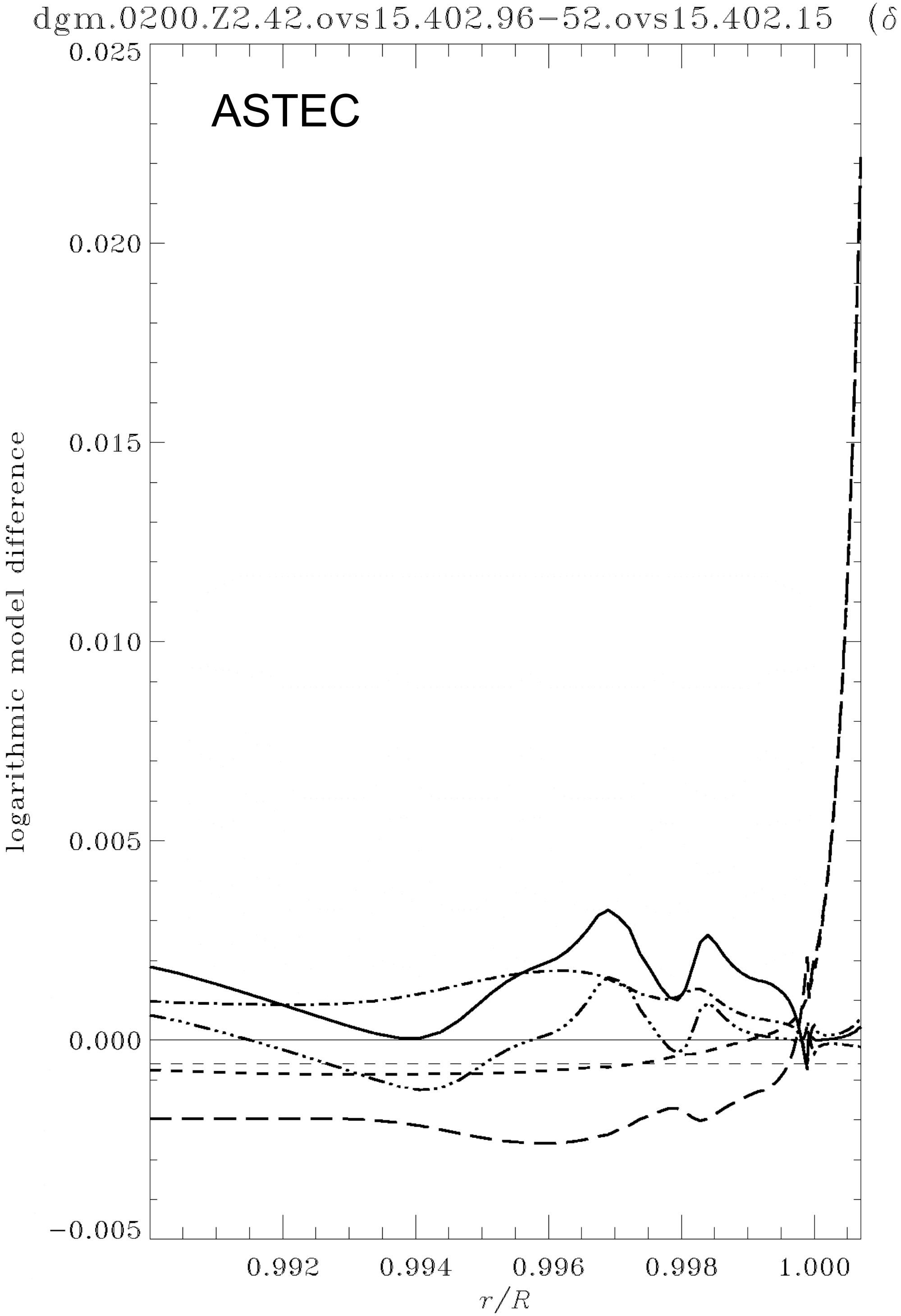
Test effect of no. of meshpoints:

(N = 600) – (N = 1200)





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Test effect of no. of meshpoints:

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Line styles:

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- ———— : $\delta \ln q$
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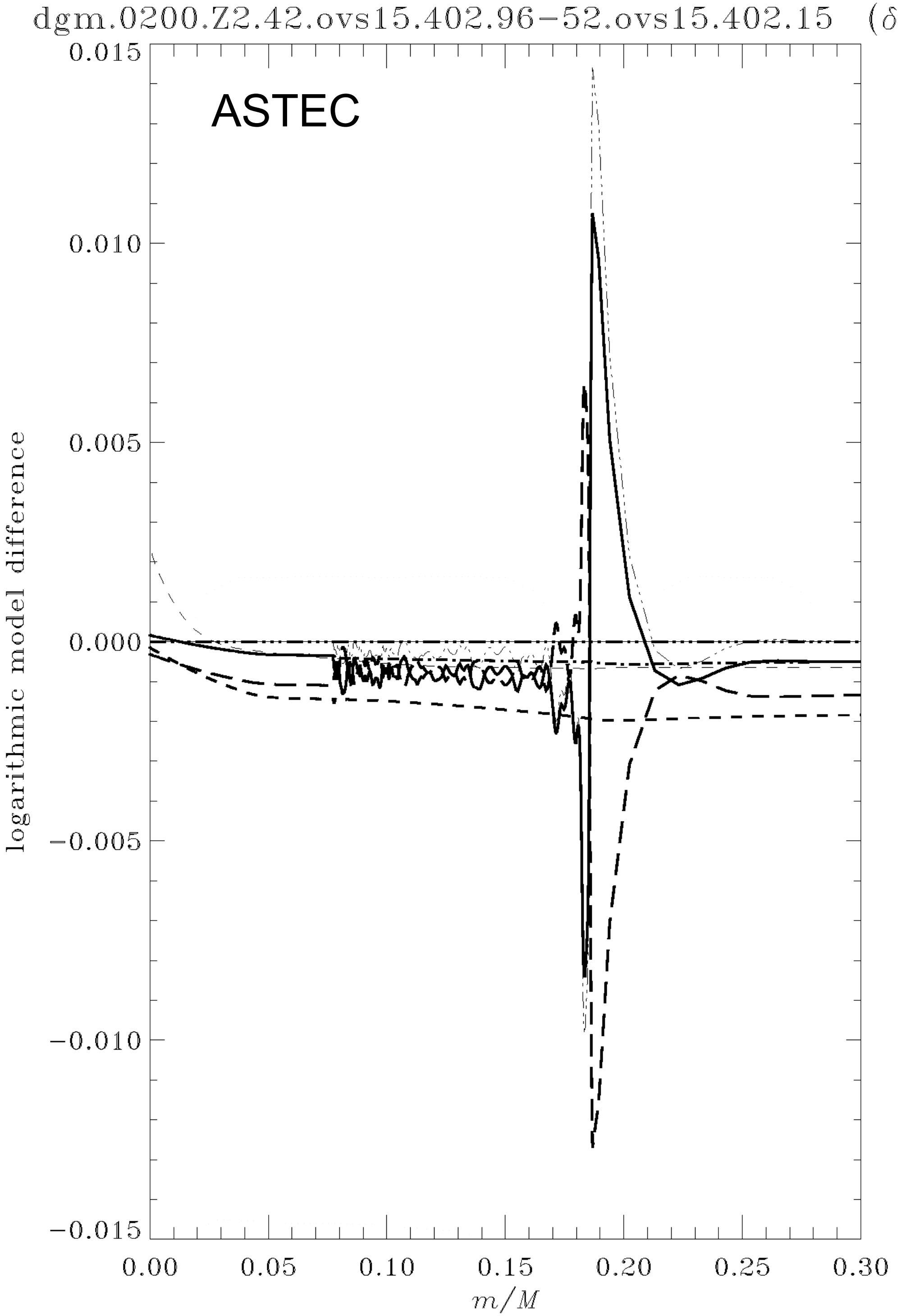
- —··—··—··· : δX



Case 1.5

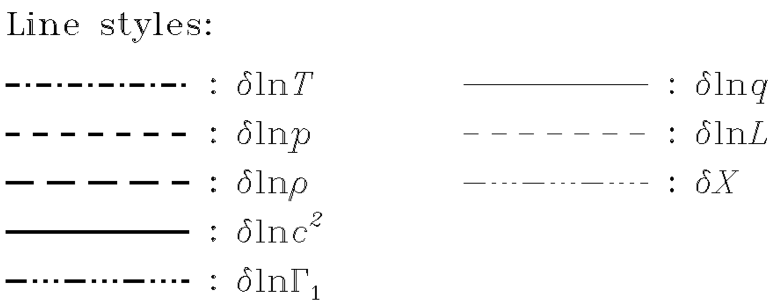
2.0 $M_\odot$, X_c = 0.01,

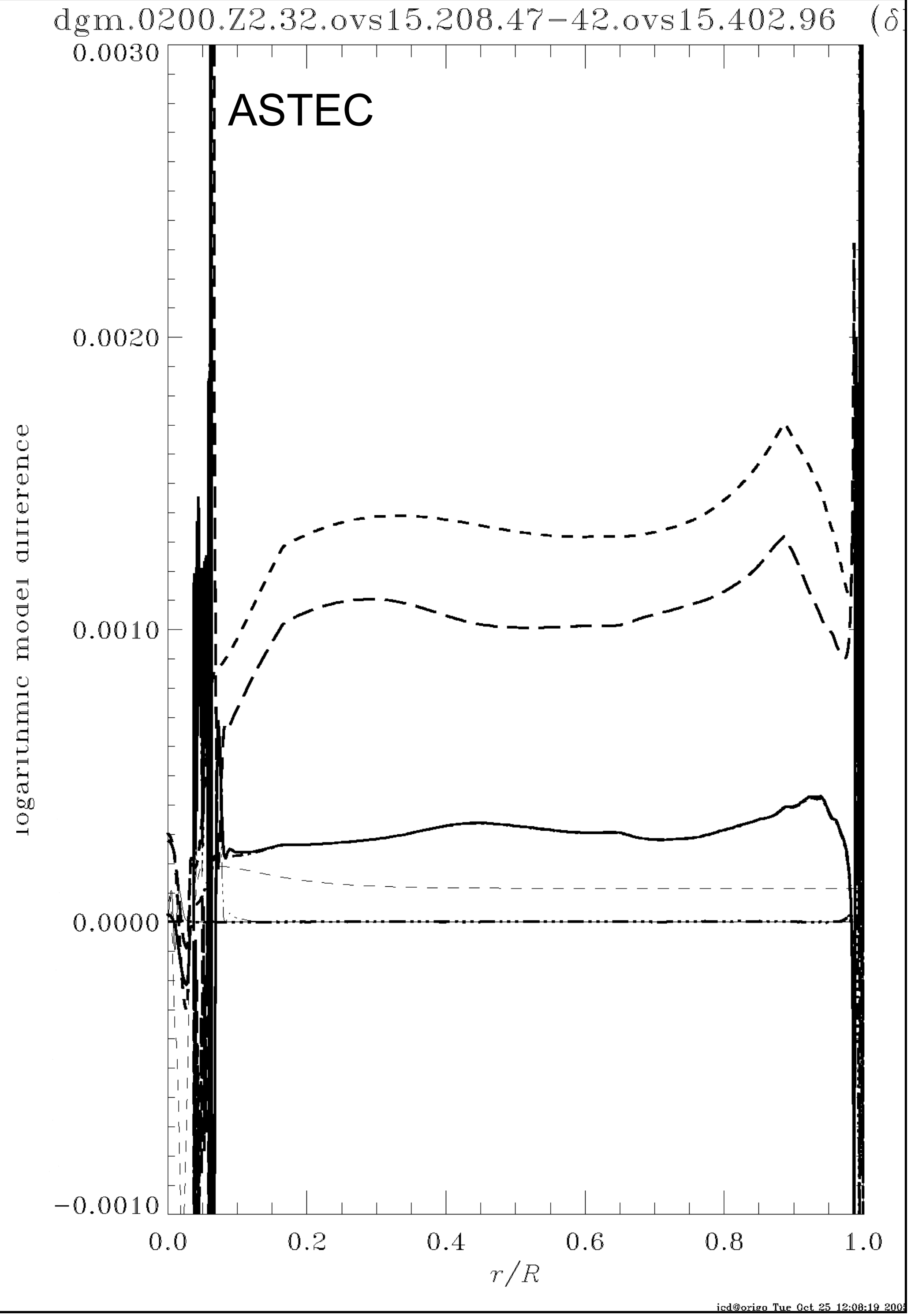
Overshoot 0.15 H_p

^{3}He in equilibrium

Test effect of no. of timesteps:

(N_t = 208) – (N_t = 402)





Case 1.5

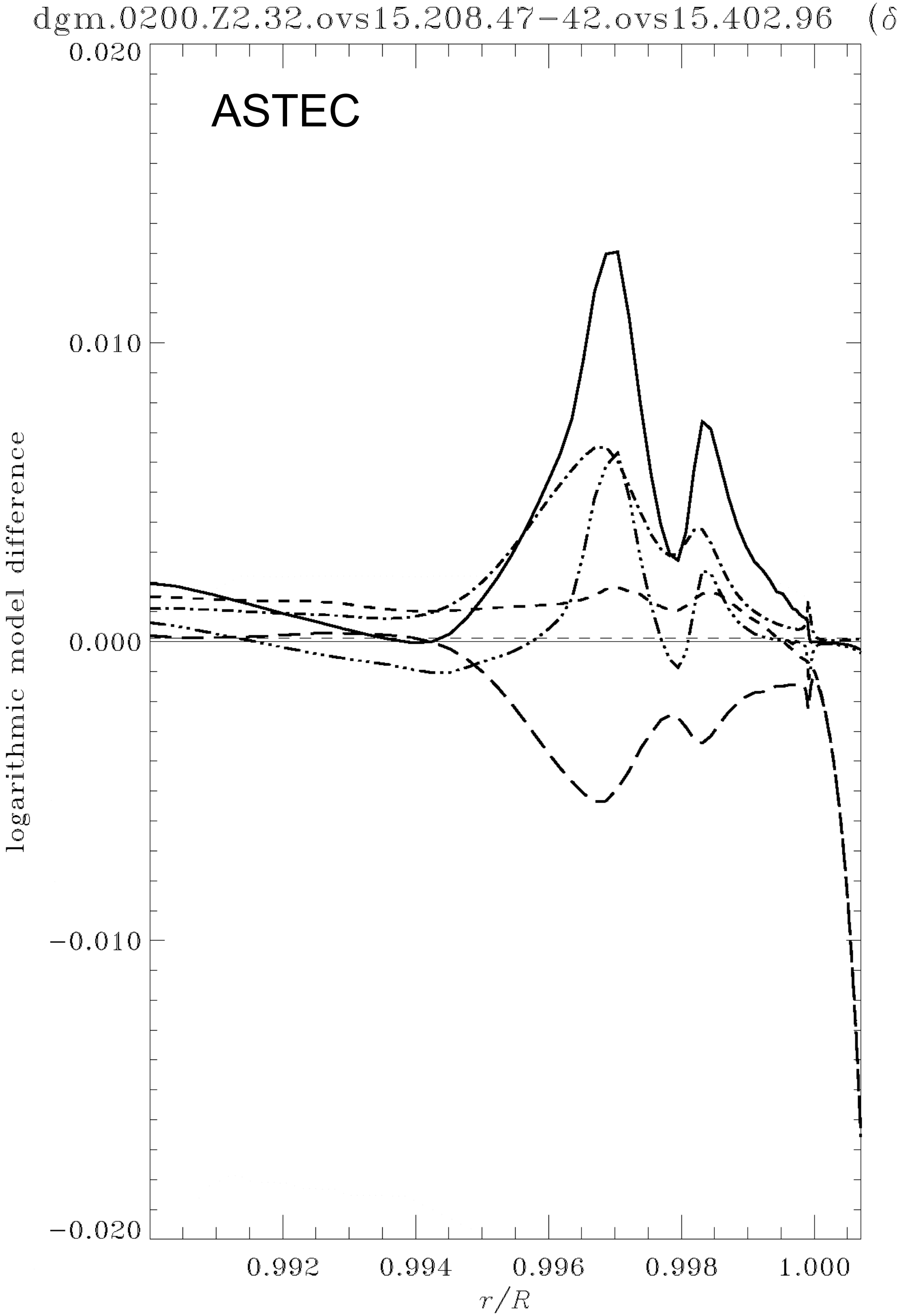
2.0 M⊙, X_c = 0.01,

Overshoot 0.15 H_p

^{3}He in equilibrium

Test effect of no. of timesteps:

(N_t = 208) – (N_t = 402)



Line styles:

- ‑·‑·‑·‑ : $\delta \ln T$
- ‑ ‑ ‑ ‑ : $\delta \ln p$
- — — — : $\delta \ln \rho$
- —— : $\delta \ln c^2$
- ‑···‑··· : $\delta \ln \Gamma_1$
- —— : $\delta \ln q$
- ‑ ‑ ‑ ‑ : $\delta \ln L$
- ‑···‑··· : δX

Case 1.5

2.0 M⊙, X_c = 0.01,

Overshoot 0.15 H_p

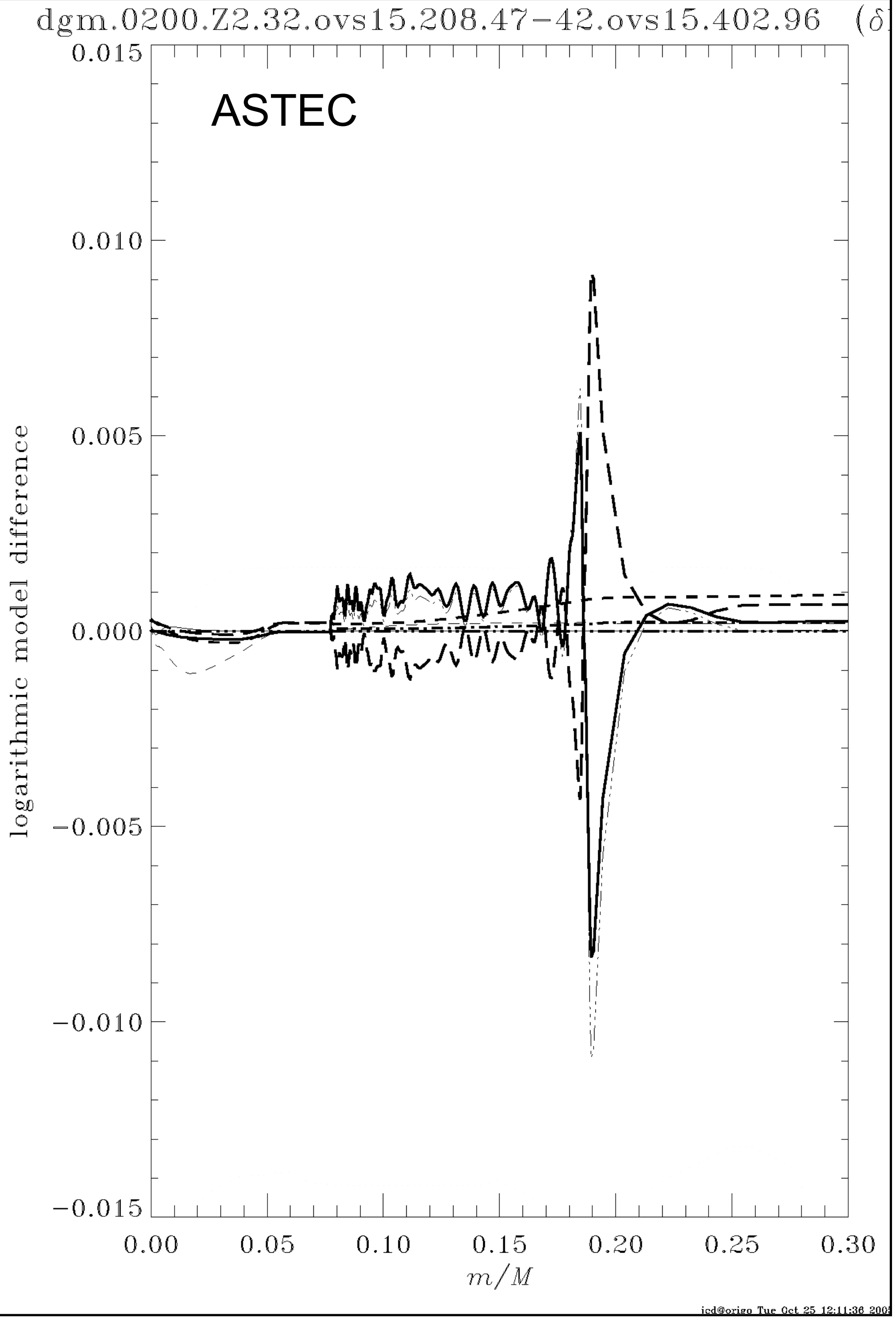
^{3}He in equilibrium

Test effect of no. of timesteps:

(N_t = 208) – (N_t = 402)

Line styles:

- ‑·‑·‑·‑·‑ : $\delta \ln T$
- ‑ ‑ ‑ ‑ : $\delta \ln p$
- — — — : $\delta \ln \rho$
- —— : $\delta \ln c^2$
- ‑···‑···‑ : $\delta \ln \Gamma_1$
- —— : $\delta \ln q$
- ‑ ‑ ‑ ‑ : $\delta \ln L$
- ‑···‑··· : δX



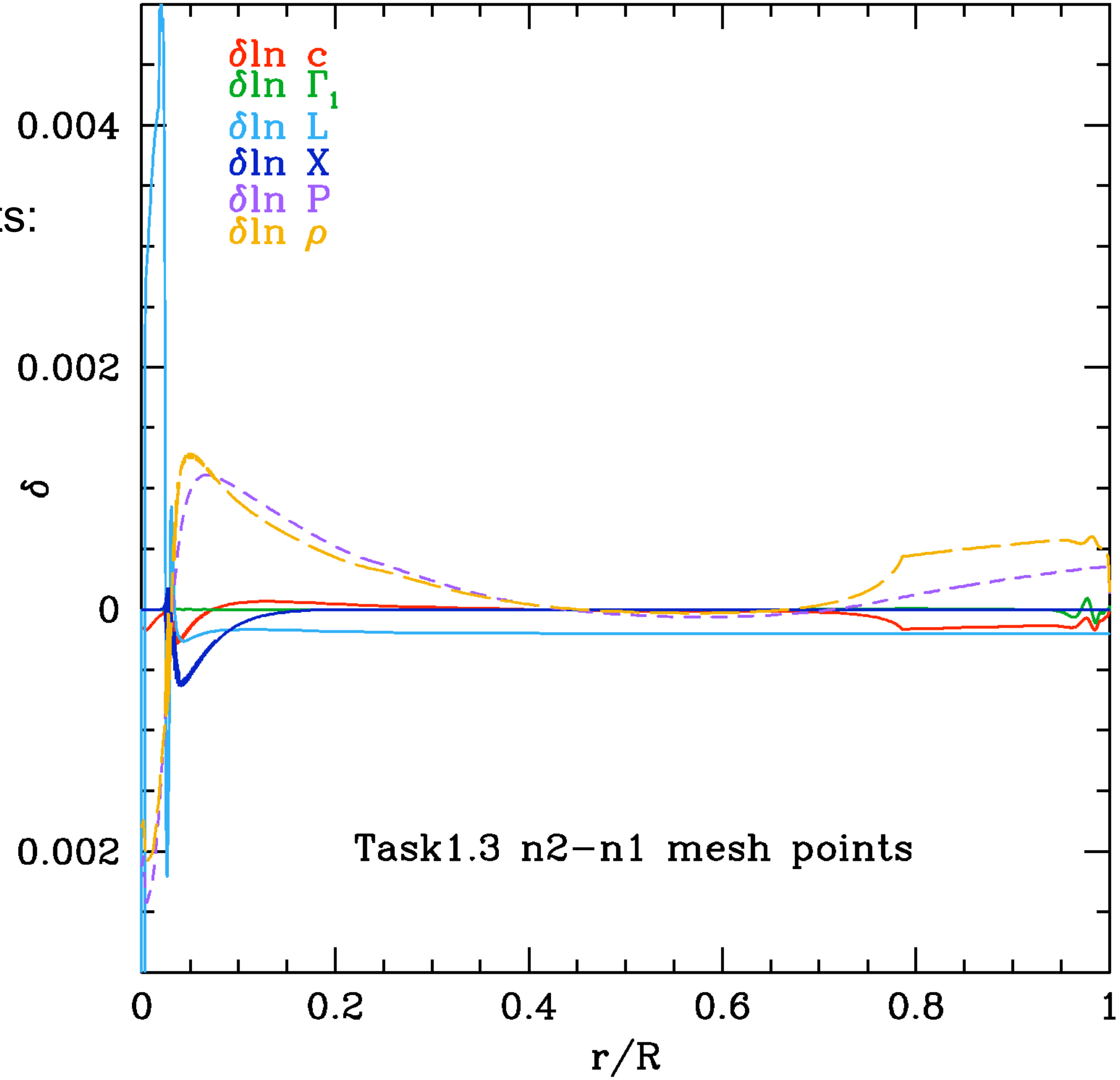
Case 1.3

CLES

1.2 M–, M_c = 0.1 M–

Test effect of no. of meshpoints:

(N = 2361) – (N = 1187)



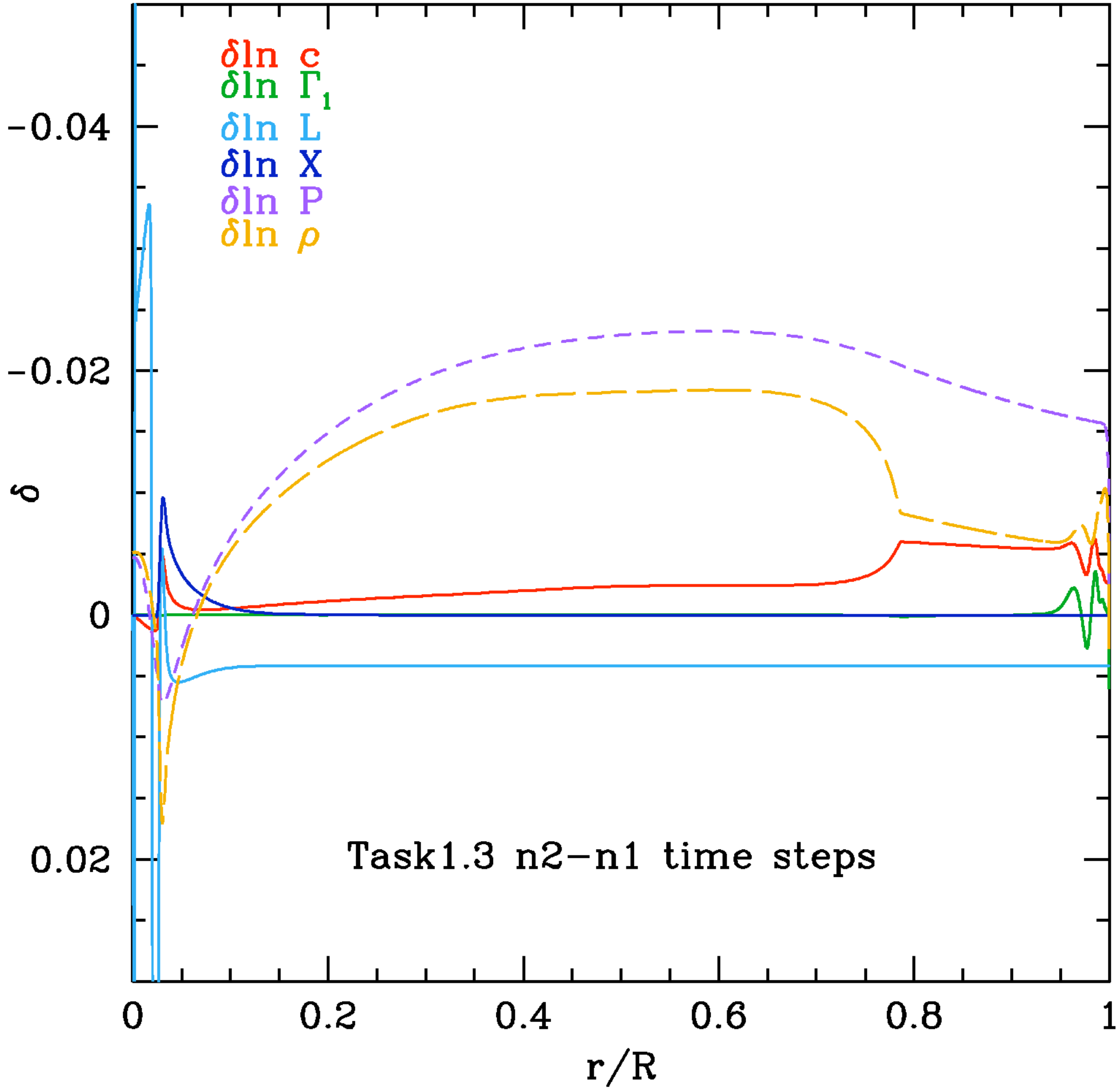
Case 1.3

CLES

1.2 M–, M_c = 0.1 M–

Test effect of no. of timesteps:

(N = 233) – (N = 115)



Case 1.5

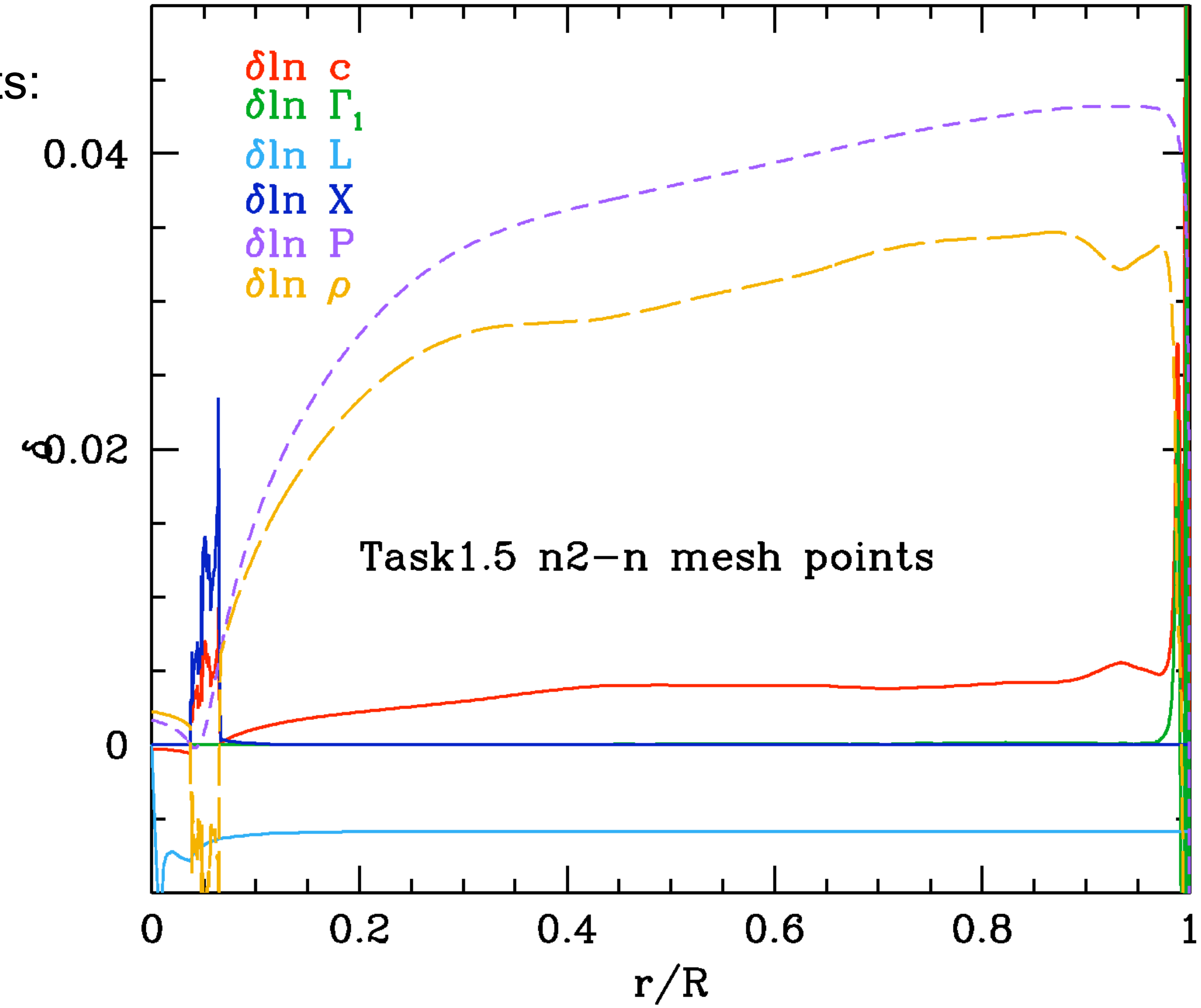
2.0 M⊙, X_c = 0.01,

Overshoot 0.15 H_p

CLES

Test effect of no. of meshpoints:

(N = 2409) – (N = 1200)



Case 1.5

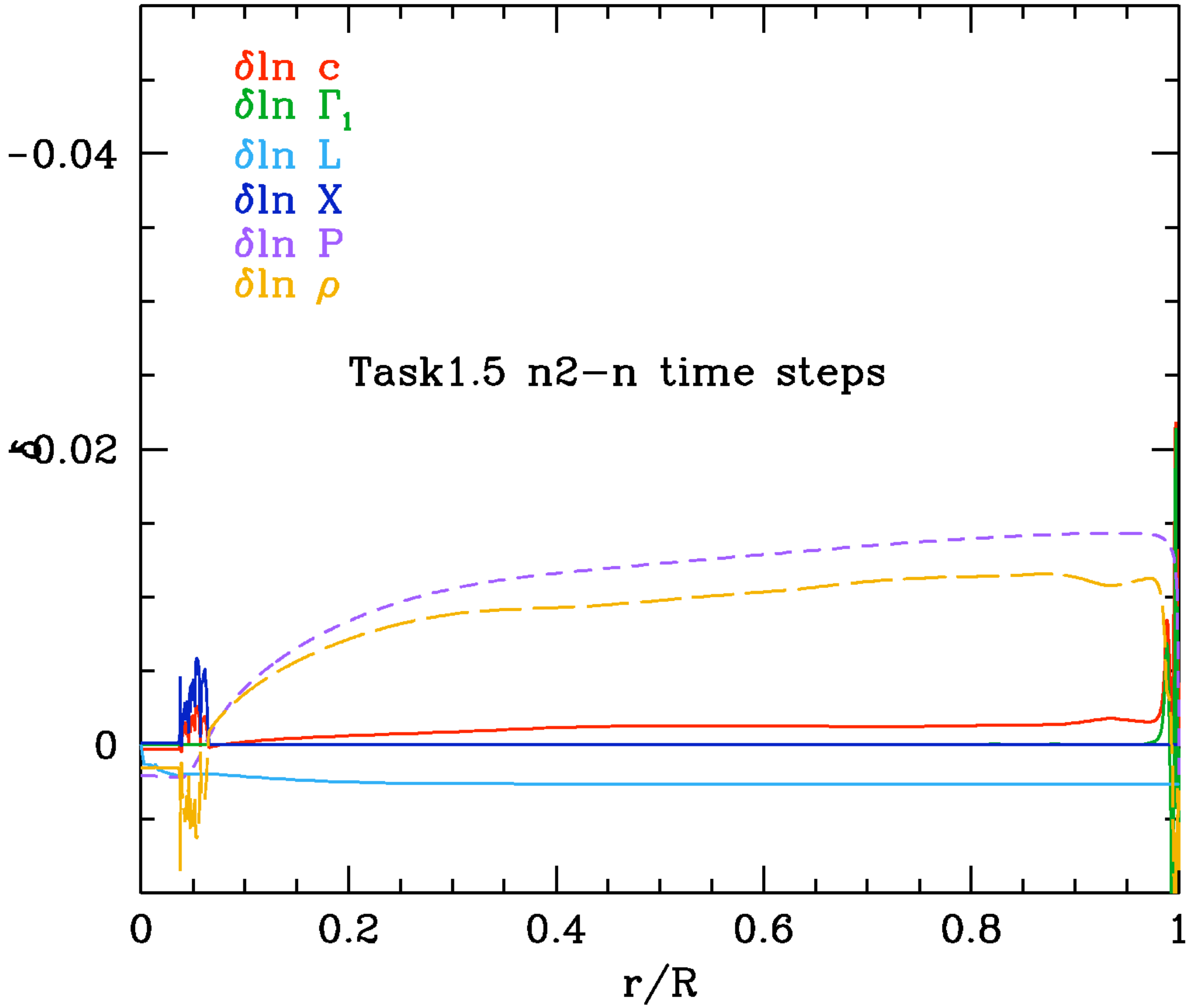
2.0 M⊙, X_c = 0.01,

Overshoot 0.15 H_p

CLES

Test effect of no. of timesteps:

(N = 374) – (N = 189)



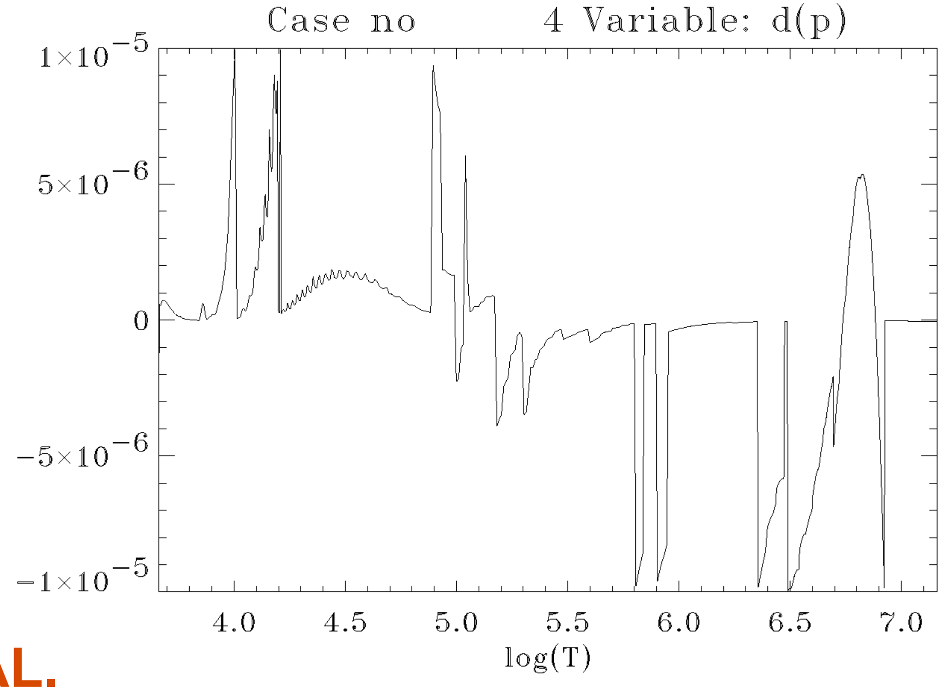
Physics comparisons

Evaluate physics (EOS, opacity, energy-generation rate, rate of composition change, …, at fixed T, ρ, X_i

Examples: comparing CESAM and CLES with ASTEC, showing, e.g.,

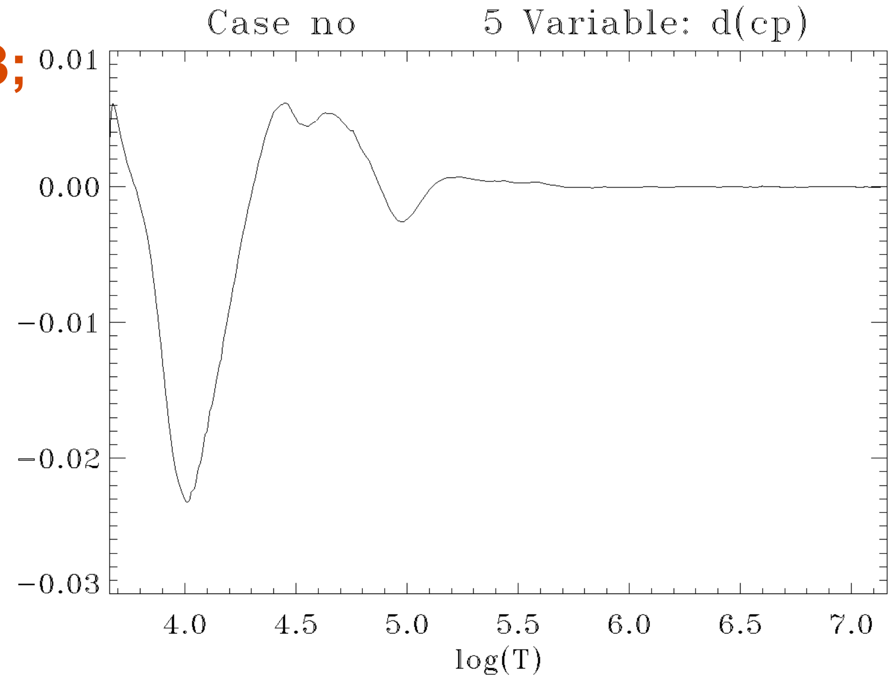
$\ln(\kappa_{ASTEC}(\rho_{CESAM}, T_{CESAM}, \ldots)/\kappa_{CESAM})$

CESAM, Case 1.1



Note: consistency problems in OPAL.

See also Boothroyd & Sackman (2003; ApJ 583, 1004)

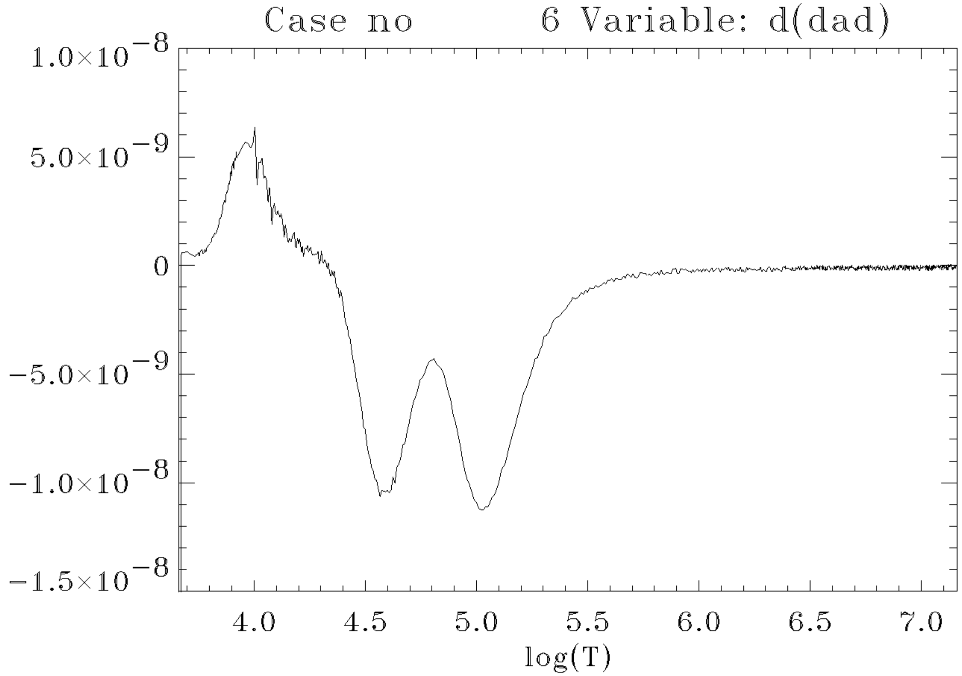


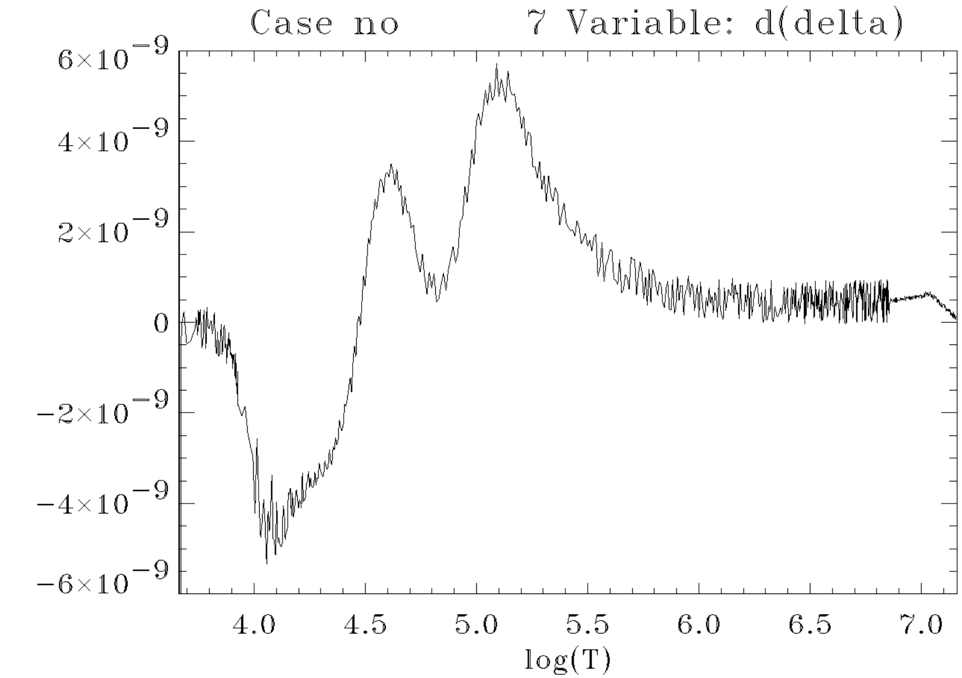
In ASTEC implementation:

Directly from OPAL: p, r_{ad}, δ, α, Γ_1

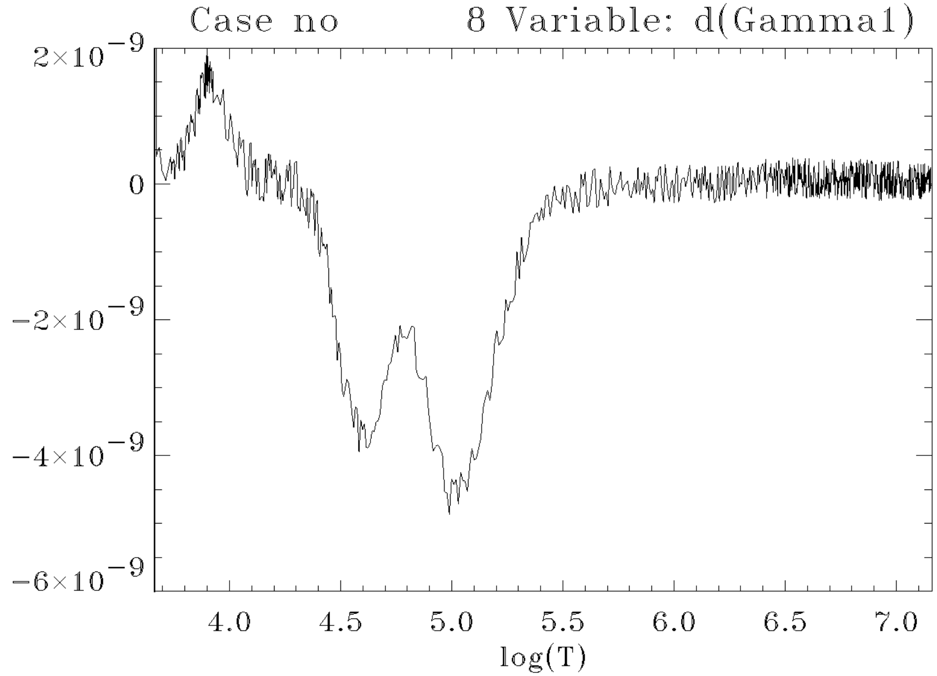
$c_p = c_v + p\,\delta^2/(\rho\, T\, \alpha)$

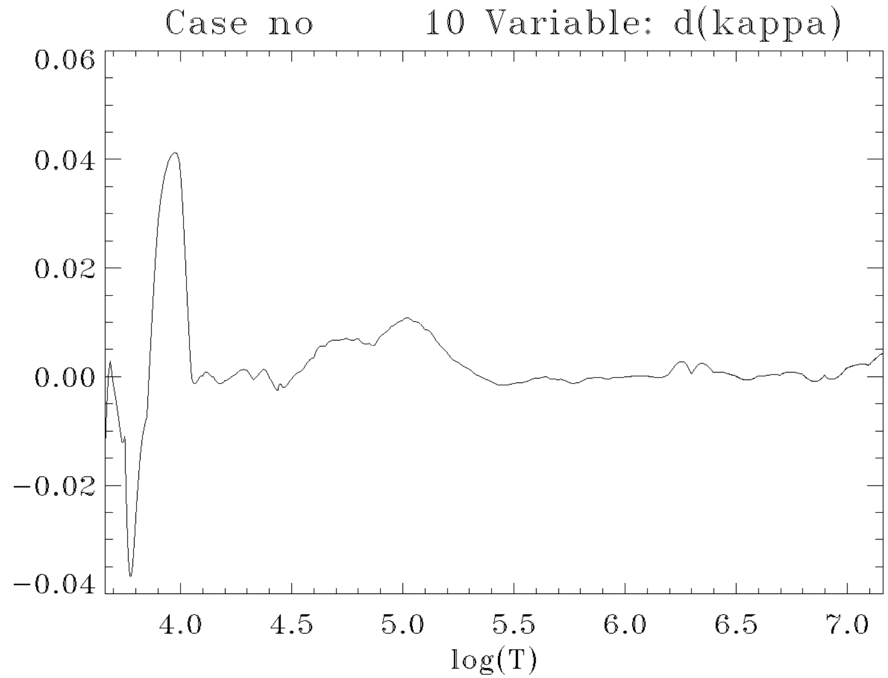
CESAM, Case 1.1



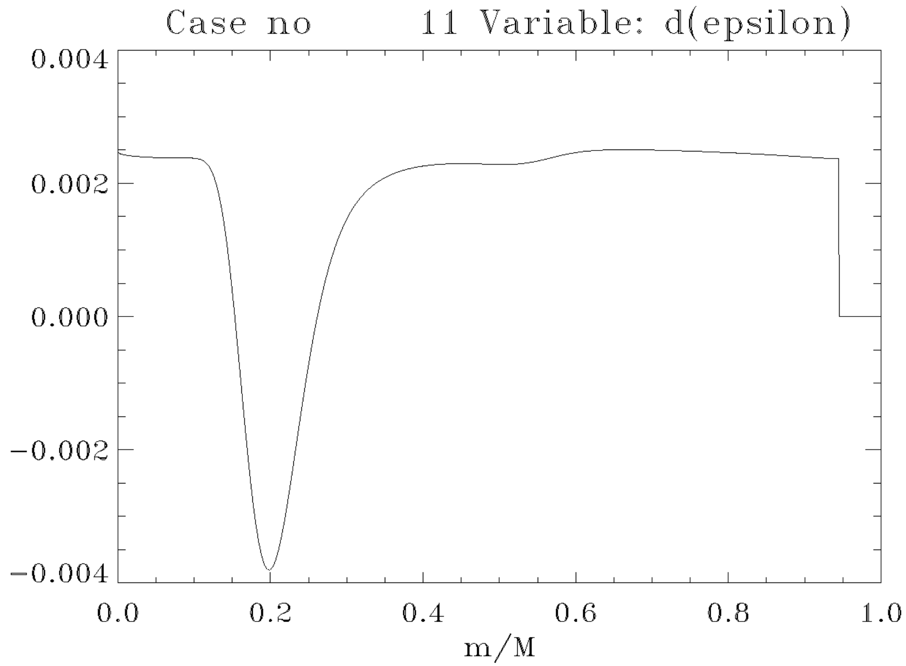


CESAM, Case 1.1

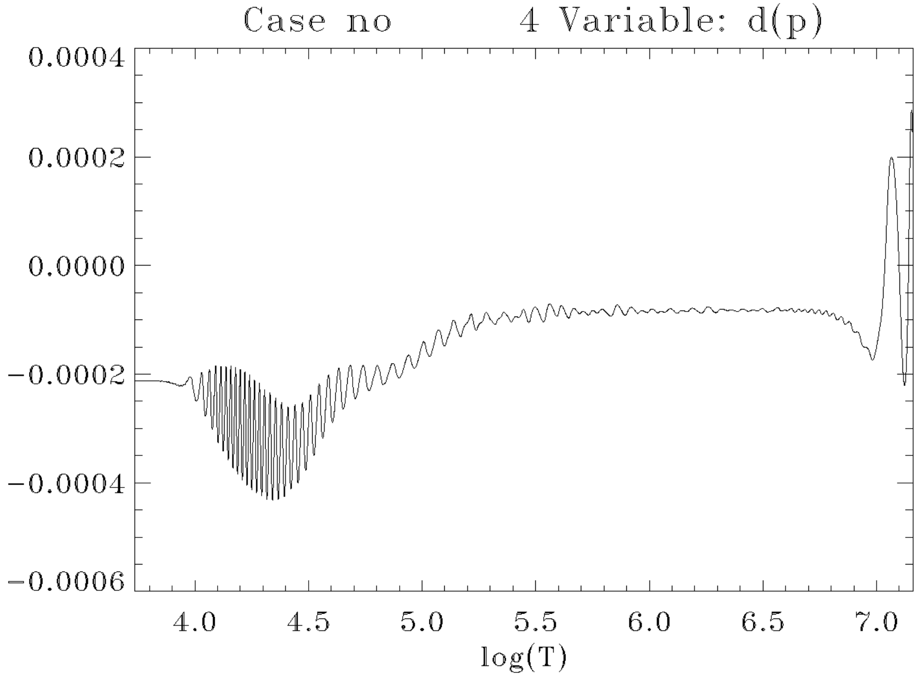




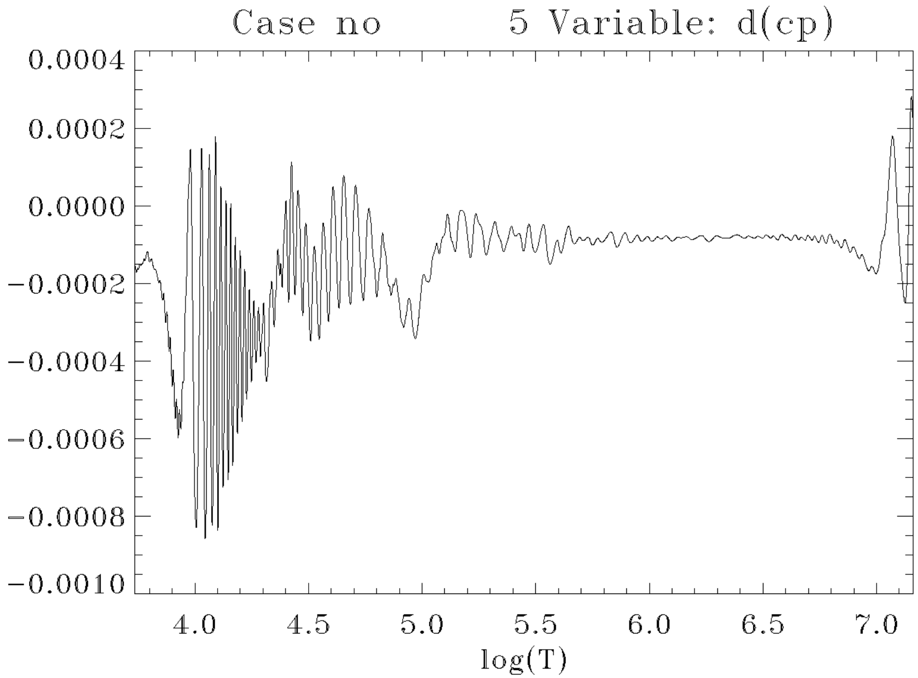
CESAM, Case 1.1



CLES, Case 1.1

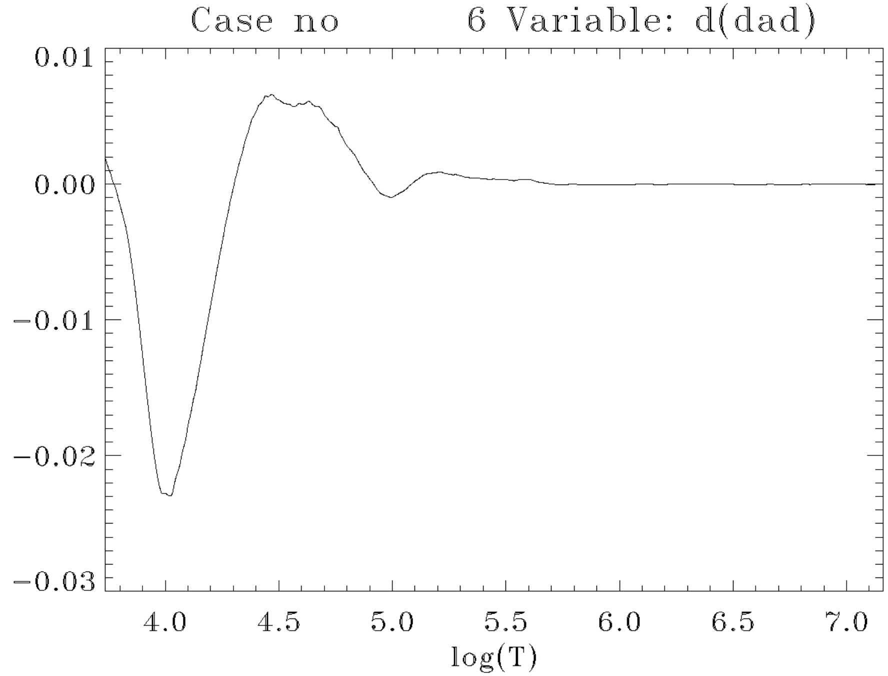


Case no 4 Variable: d(p)
0.0004
0.0002
0.0000
−0.0002
−0.0004
−0.0006
4.0
4.5
5.0
5.5
6.0
6.5
7.0
log(T)

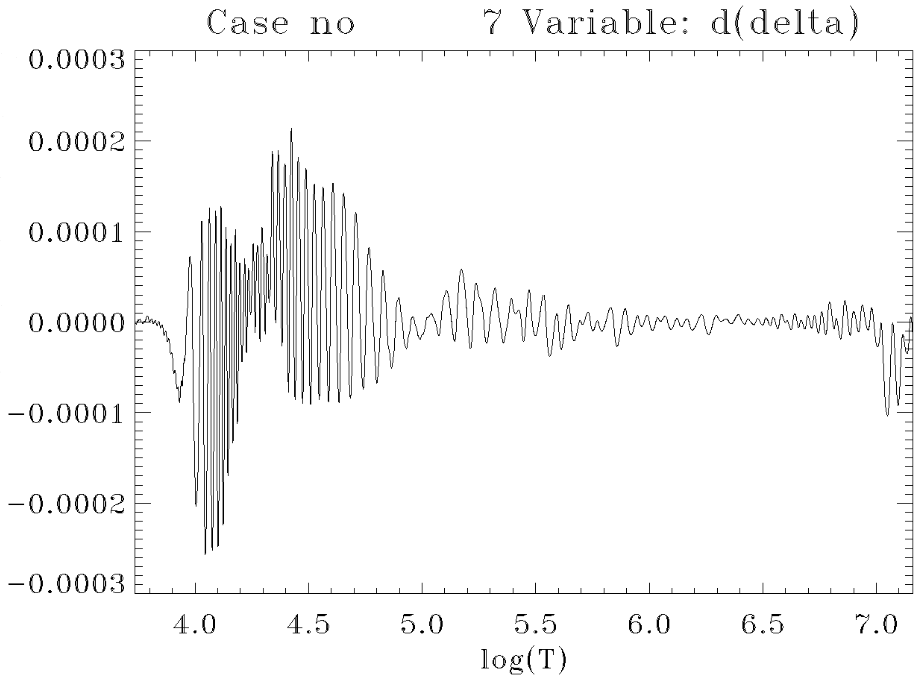


Case no 5 Variable: d(cp)
0.0004
0.0002
0.0000
−0.0002
−0.0004
−0.0006
−0.0008
−0.0010
4.0
4.5
5.0
5.5
6.0
6.5
7.0
log(T)

CLES, Case 1.1

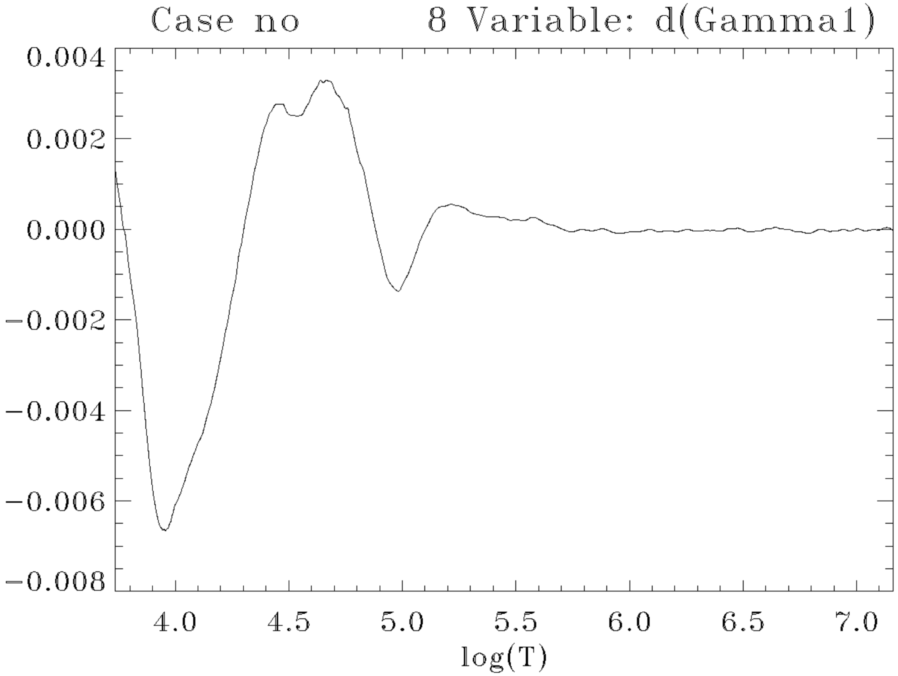


Case no 6 Variable: d(dad)
0.01
0.00
−0.01
−0.02
−0.03
4.0
4.5
5.0
5.5
6.0
6.5
7.0
log(T)

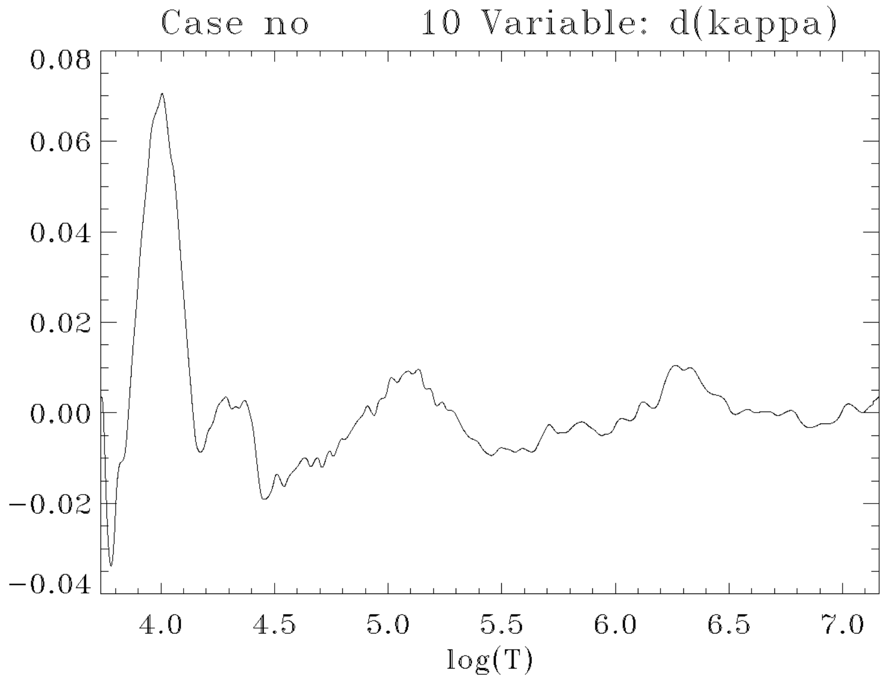


Case no 7 Variable: d(delta)
0.0003
0.0002
0.0001
0.0000
−0.0001
−0.0002
−0.0003
4.0
4.5
5.0
5.5
6.0
6.5
7.0
log(T)

CLES, Case 1.1



OPAL 2005 appears to be much more consistent!



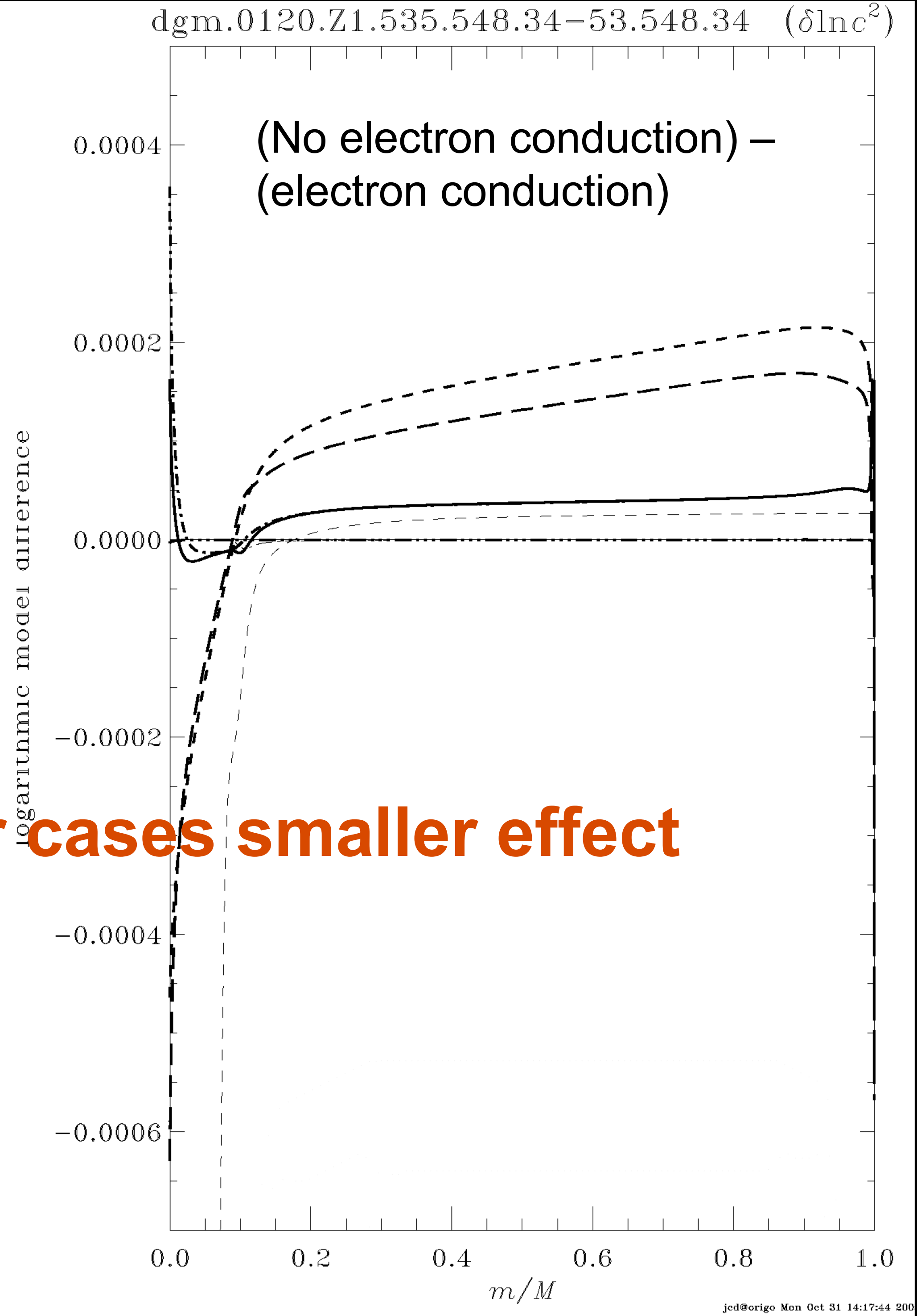
Effects of electron conduction

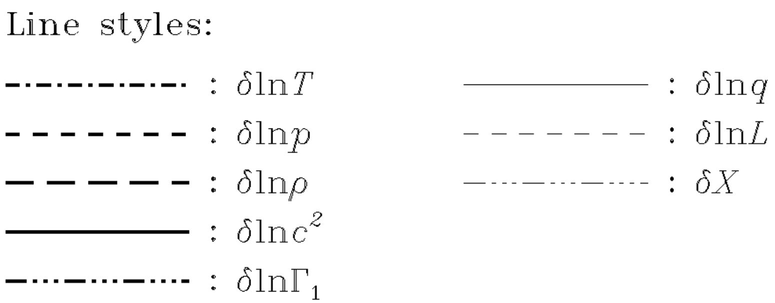
Case 1.3

M = 1.2 M–, M_c = 0.1 M–

Z = 0.01

ρ_c = 3253 g cm^{-3}





In other cases smaller effect

Main project: compare different codes

- Evolution tracks
- Global parameters for selected models
- Detailed comparison of structure
- Comparison of oscillation frequencies

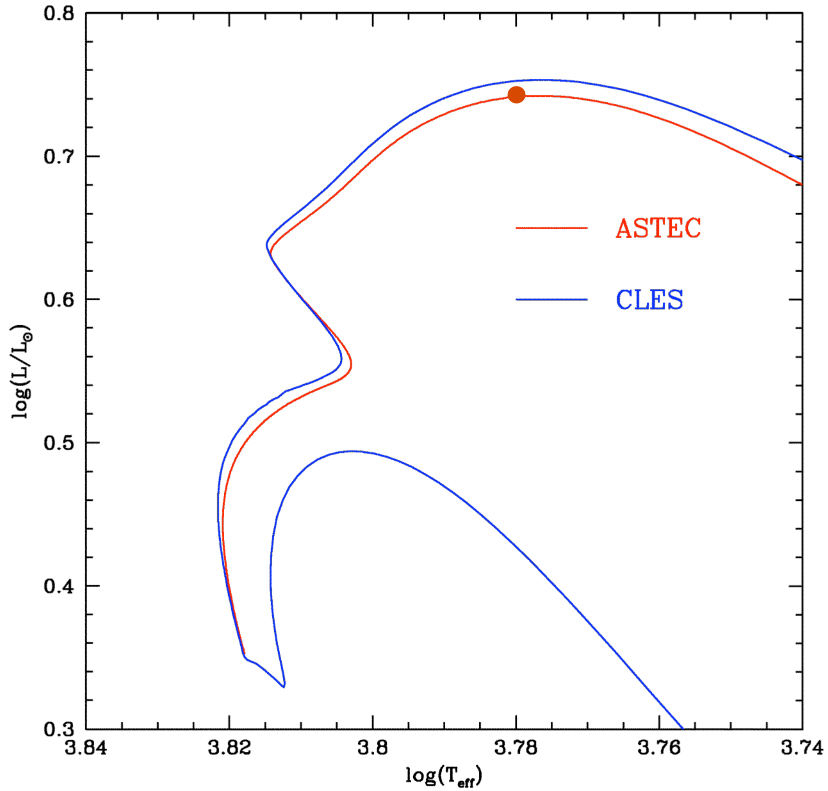
CLES and ASTEC

Case 1.3

1.2 M–

X_0 = 0.73, Z_0 = 0.01

M_{HeC} = 0.1 M–



CLES and ASTEC

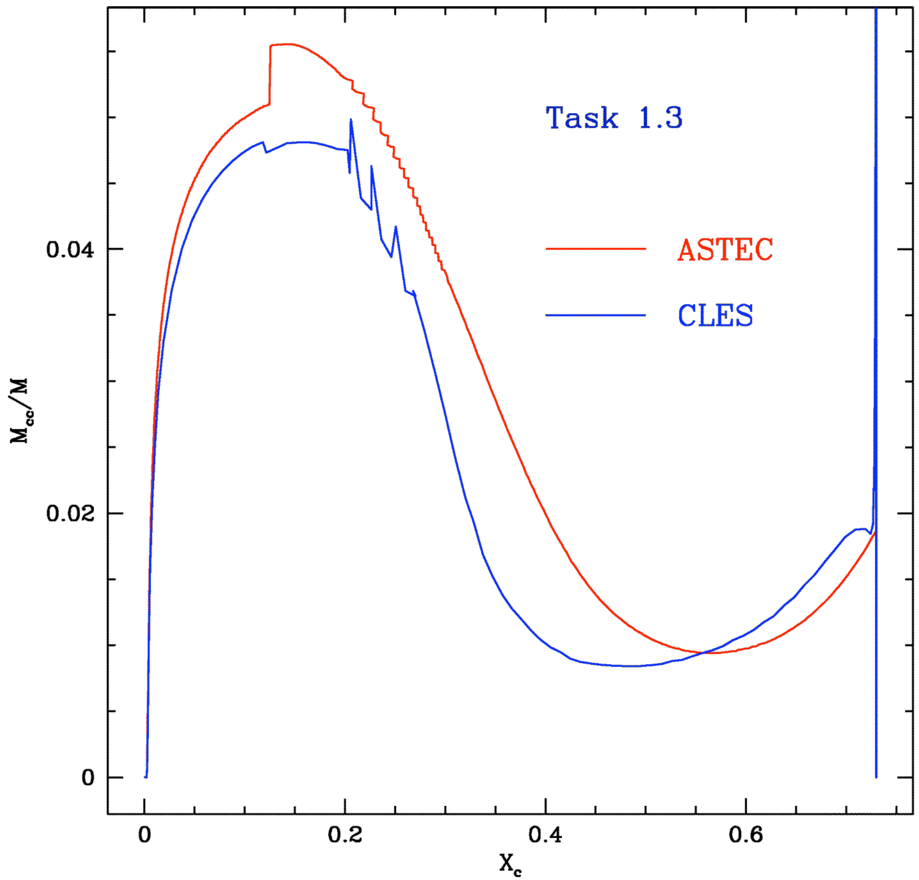
Case 1.3

1.2 M–

X_0 = 0.73, Z_0 = 0.01

M_{HeC} = 0.1 M–

M_c/M



X_c

CLES, CESAM and ASTEC

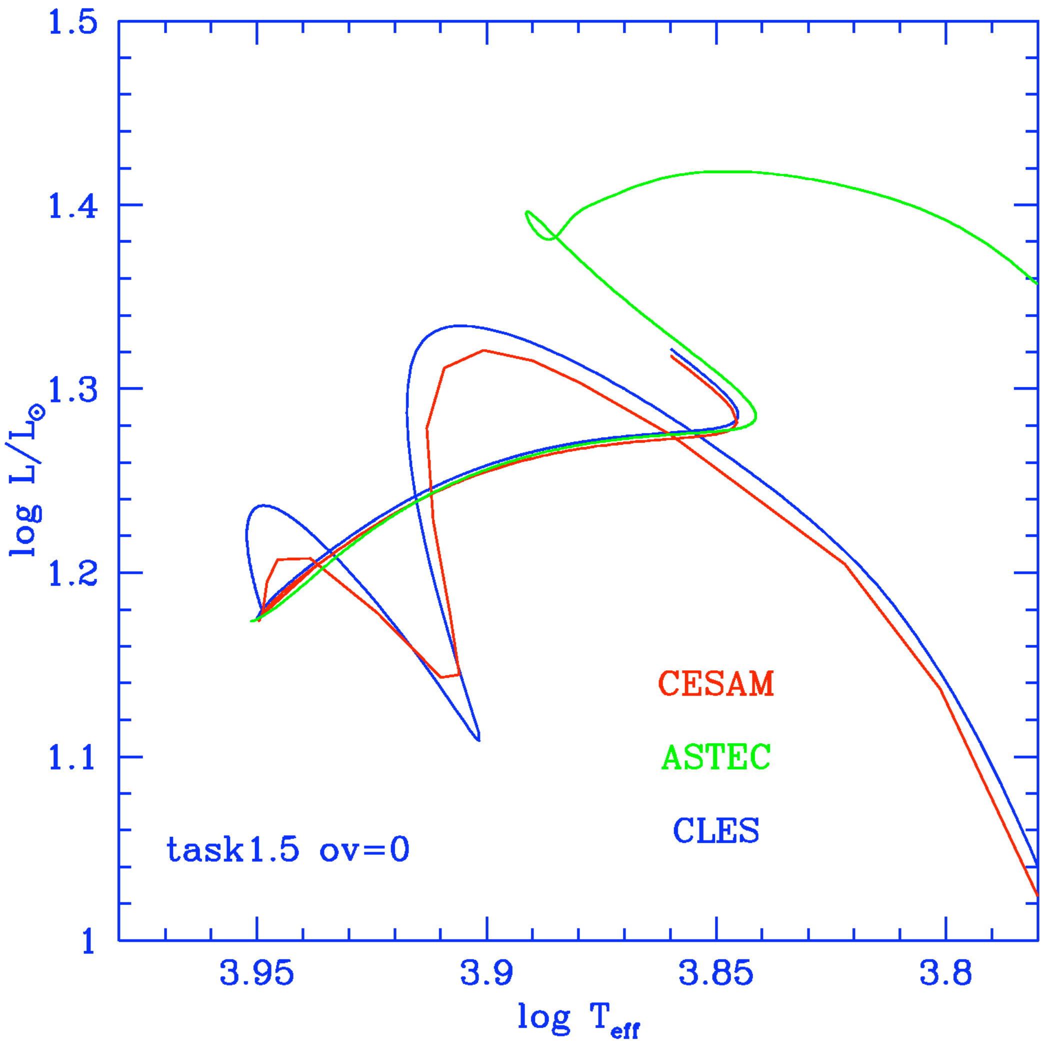
Case 1.5n

2.0 M–

X_0 = 0.72, Z_0 = 0.02

X_c = 0.01

No overshoot



CLES, CESAM and ASTEC

Case 1.5n

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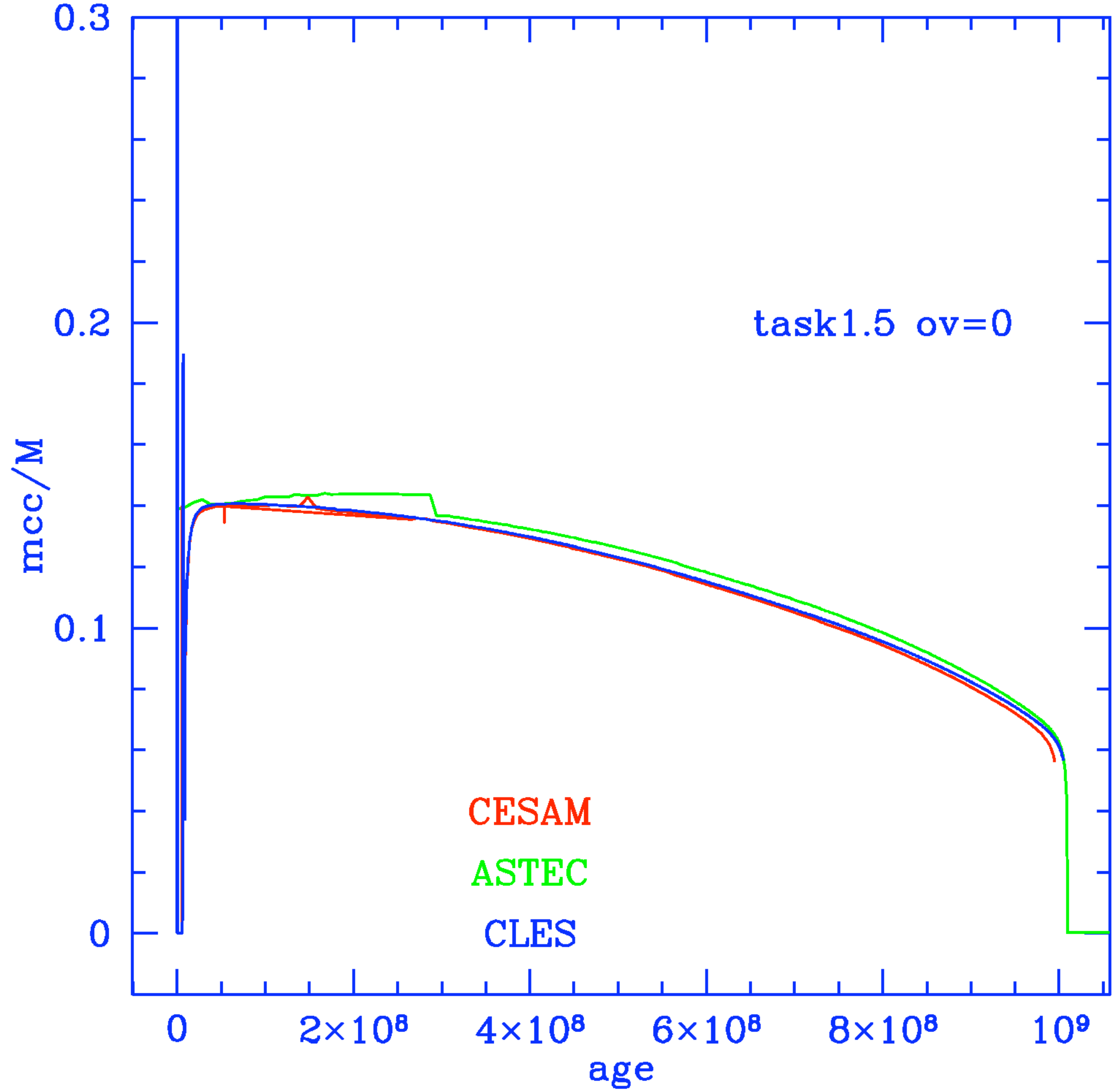
X_0 = 0.72, Z_0 = 0.02

X_c = 0.01

No overshoot



CLES, CESAM and ASTEC

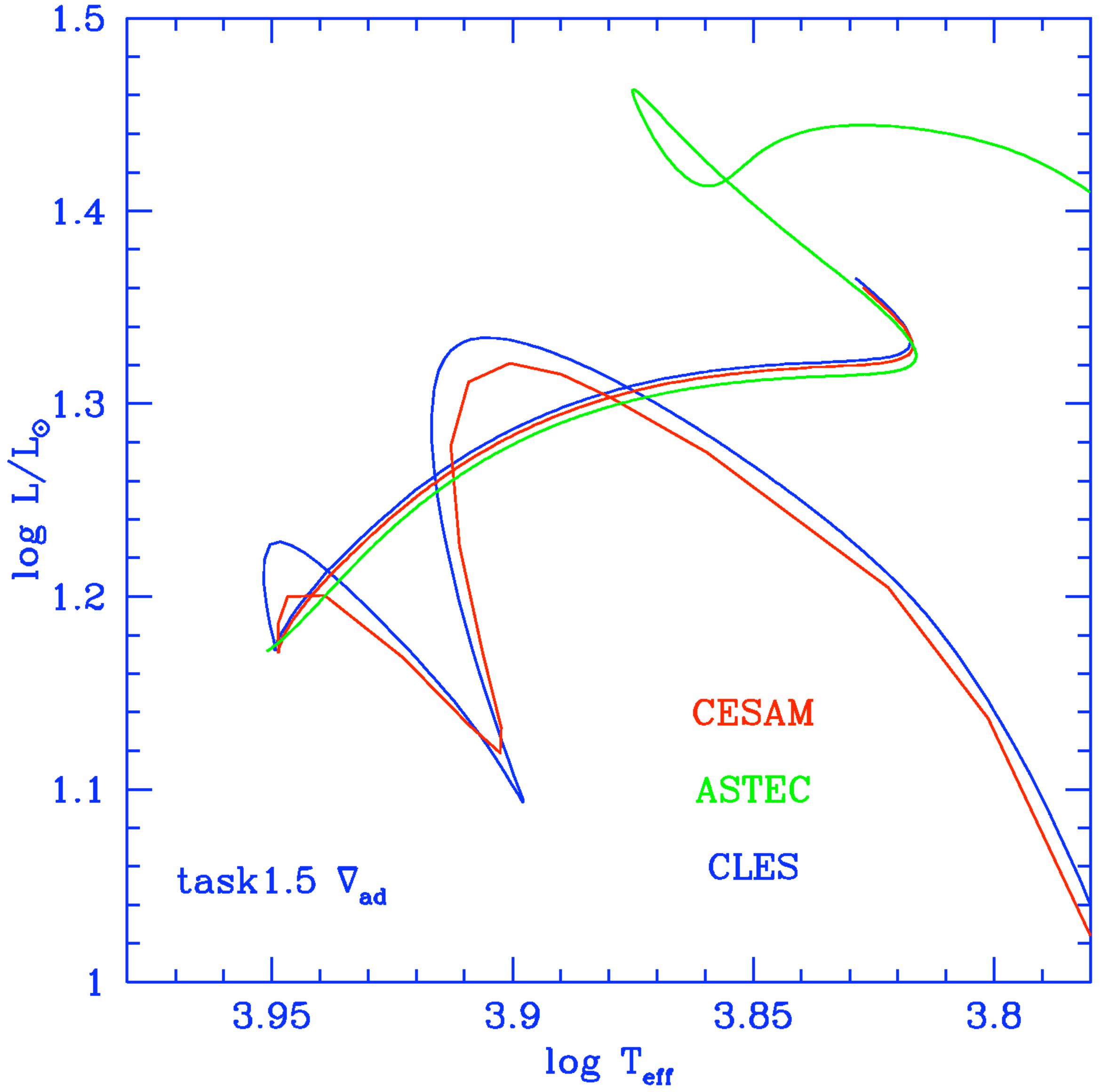
Case 1.5n

2.0 M–

X_0 = 0.72, Z_0 = 0.02

X_c = 0.01

Overshoot 0.15 H_p



CLES, CESAM and ASTEC

Case 1.5n

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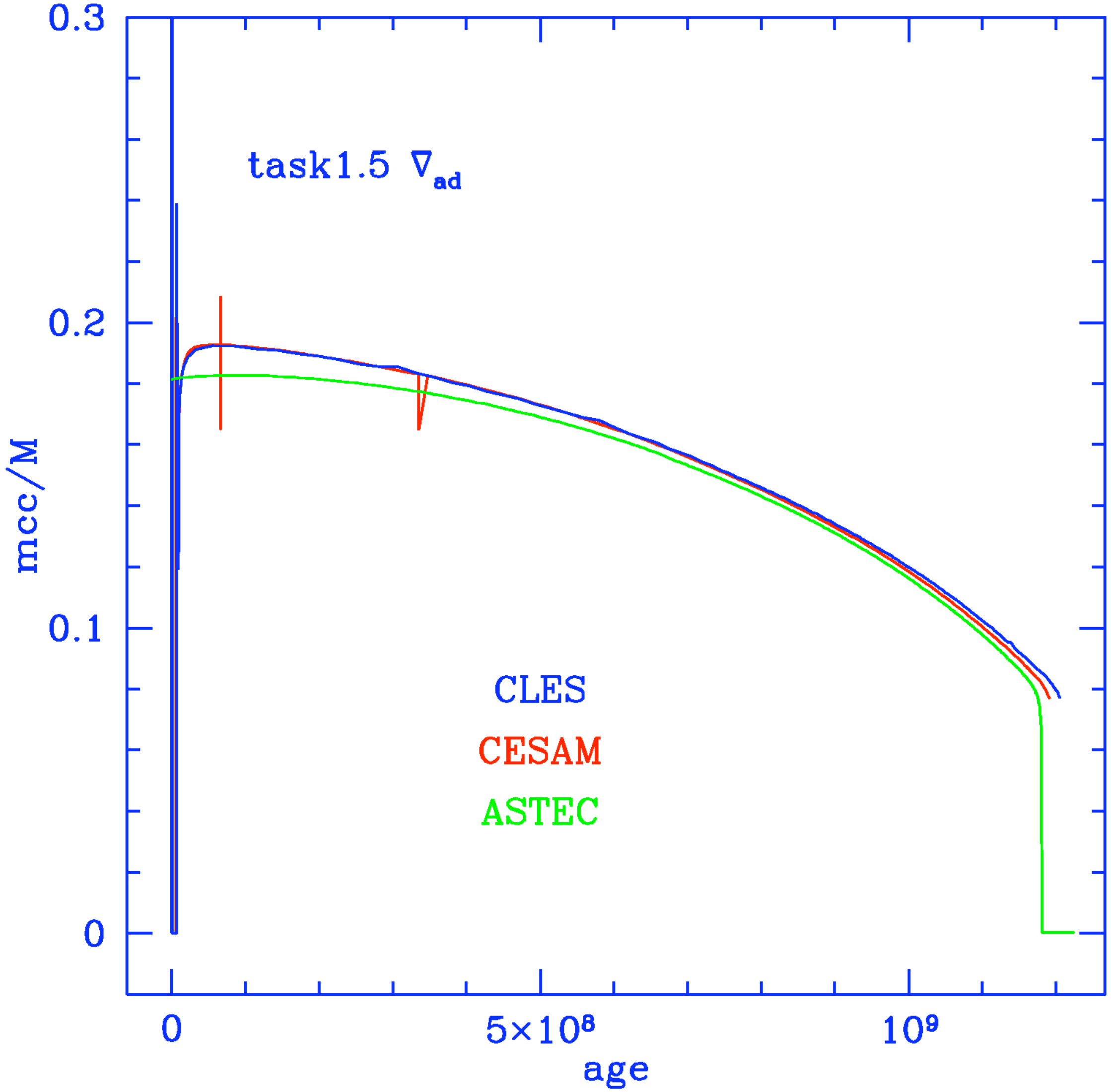
X_c = 0.01

Overshoot 0.15 H_p



Detailed model comparison

- Global quantities
- Differences at fixed m/M, plotted against m/M or r/R
- Differences at fixed r/R might be more illustrative for effects on oscillations (but not used yet)

Hydrogen abundance

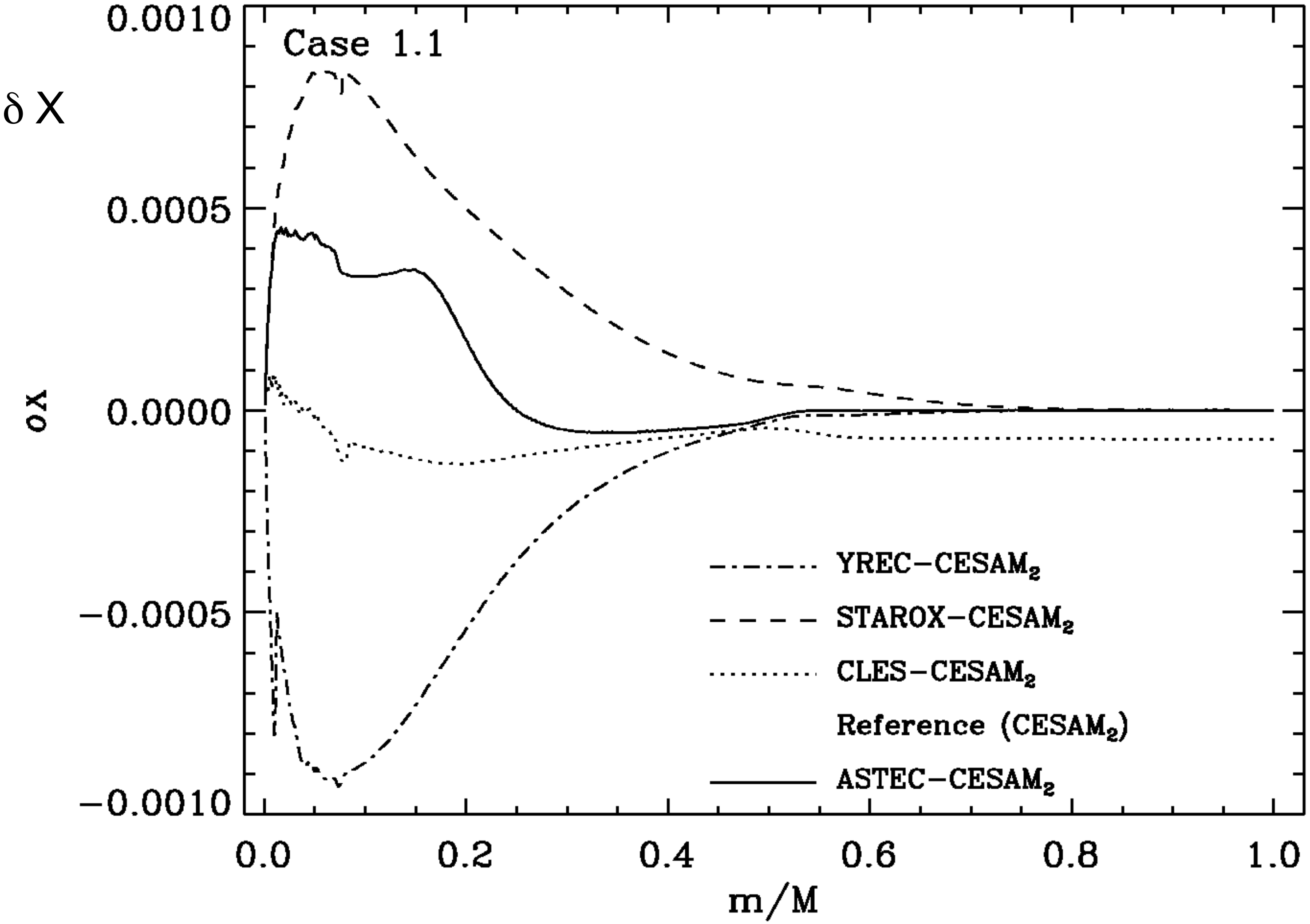
0.9 M⊙

$X_0 = 0.7$

$Z_0 = 0.02$

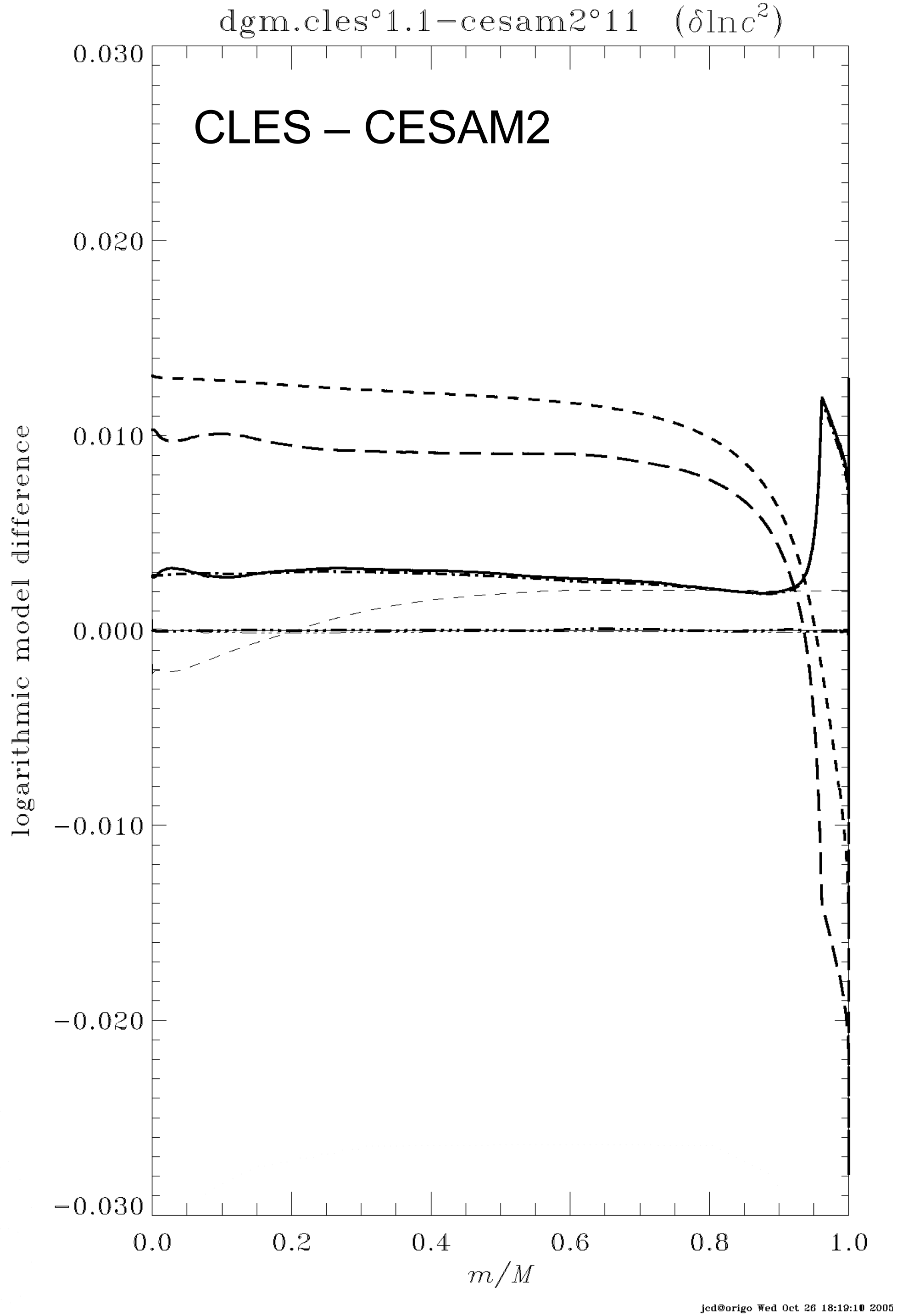
$X_c = 0.35$

δX



Case 1.1

0.9 M–, $X_c = 0.35$



Line styles:

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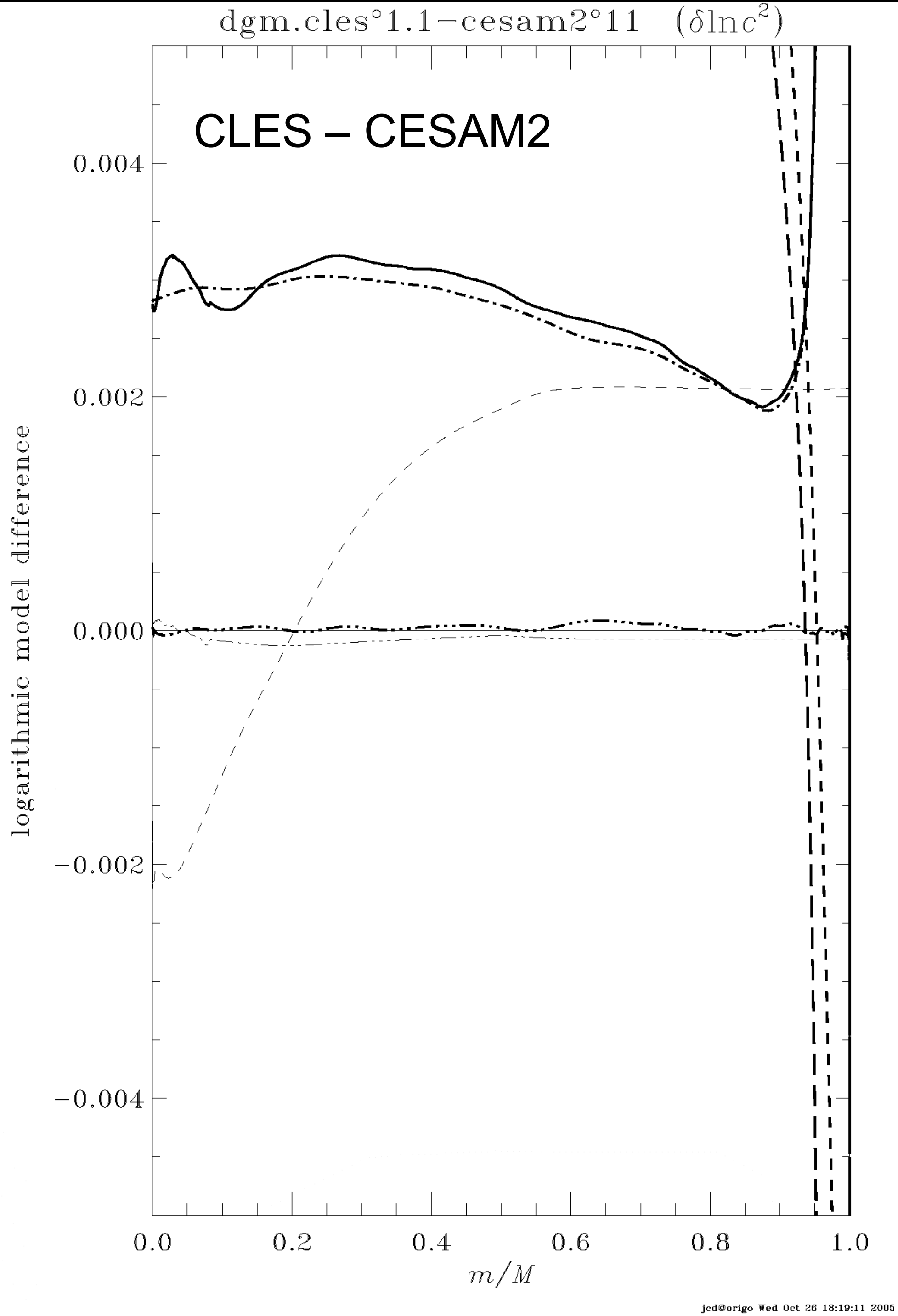
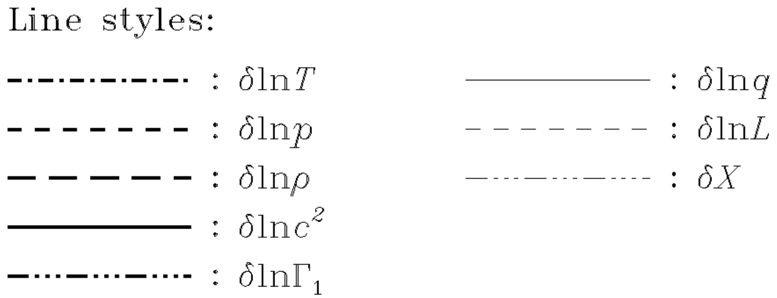
- : $\delta \ln p$
- : $\delta \ln \rho$
- : $\delta \ln c^2$
- : $\delta \ln \Gamma_1$
- : $\delta \ln q$
- : $\delta \ln L$
- : δX

Case 1.1

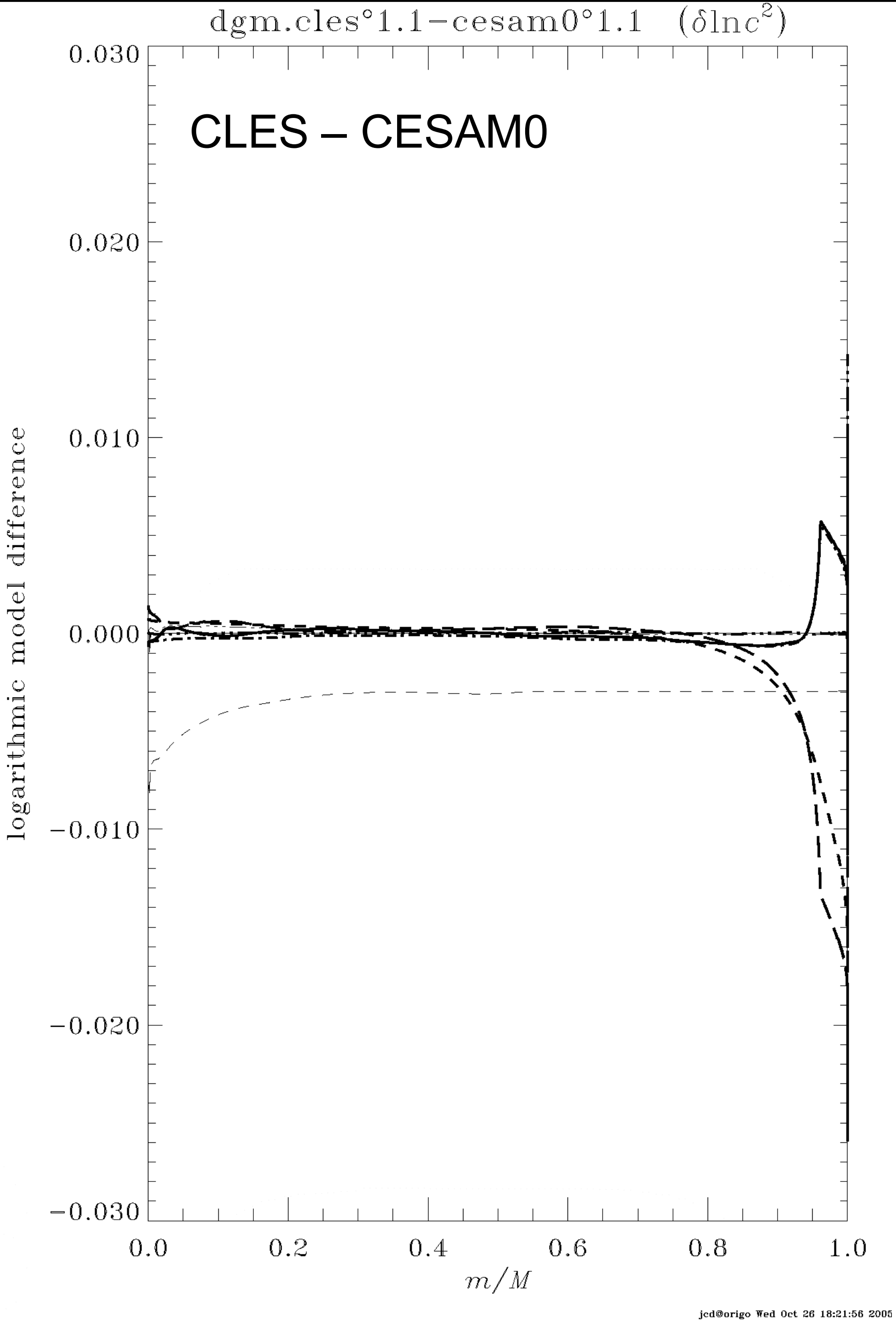
0.9 $M_{\odot}$, $X_c = 0.35$

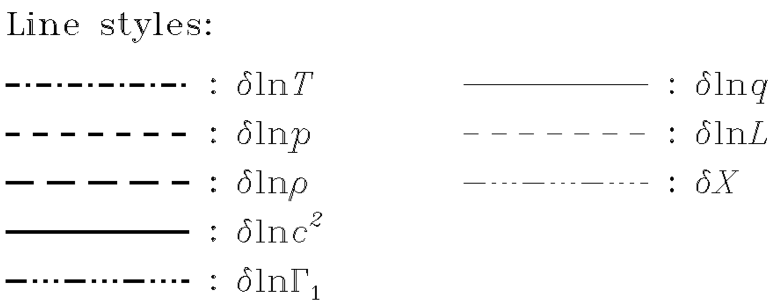




Case 1.1

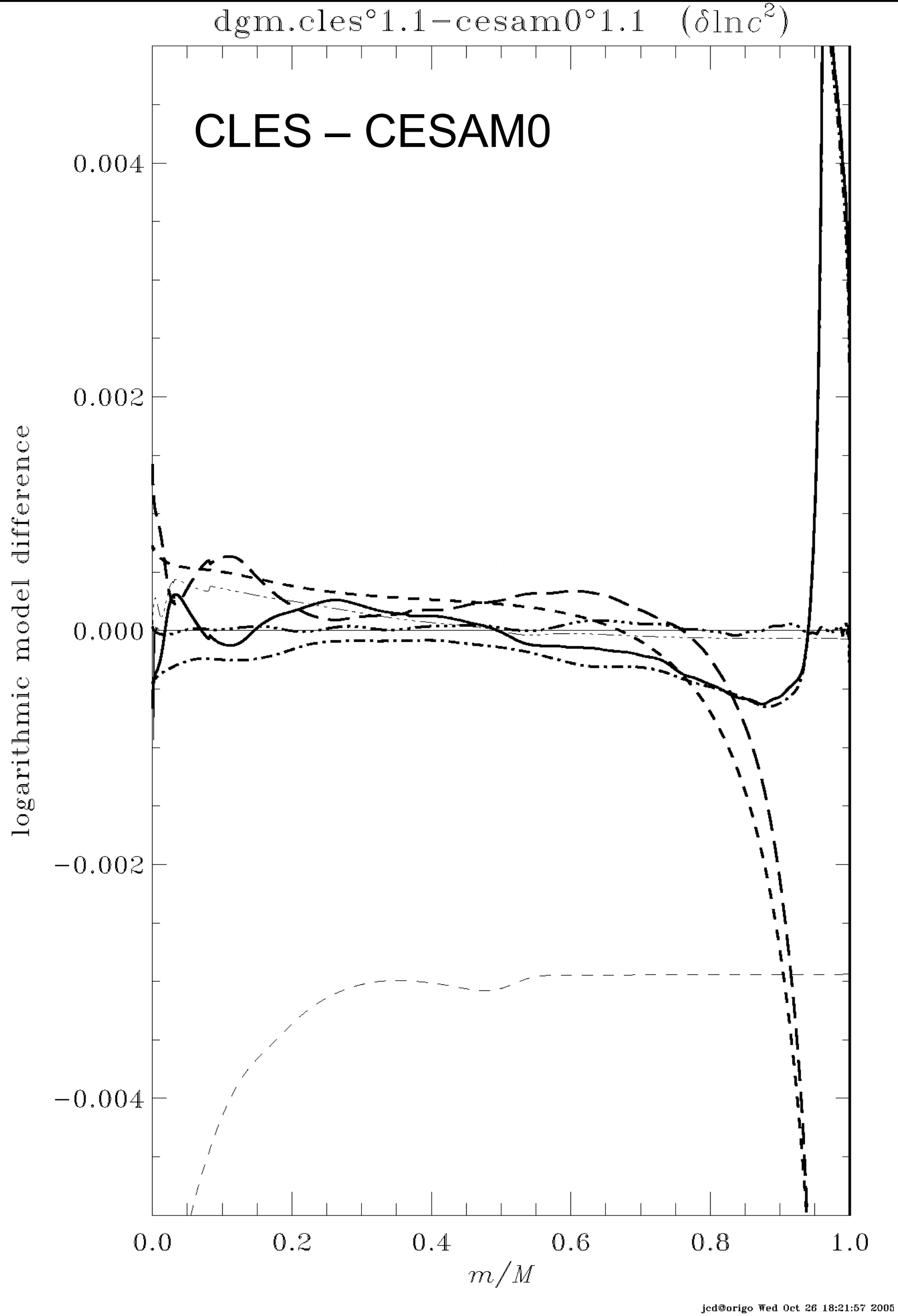
0.9 M–, X_c = 0.35





Case 1.1

0.9 M–, X_c = 0.35



Line styles:

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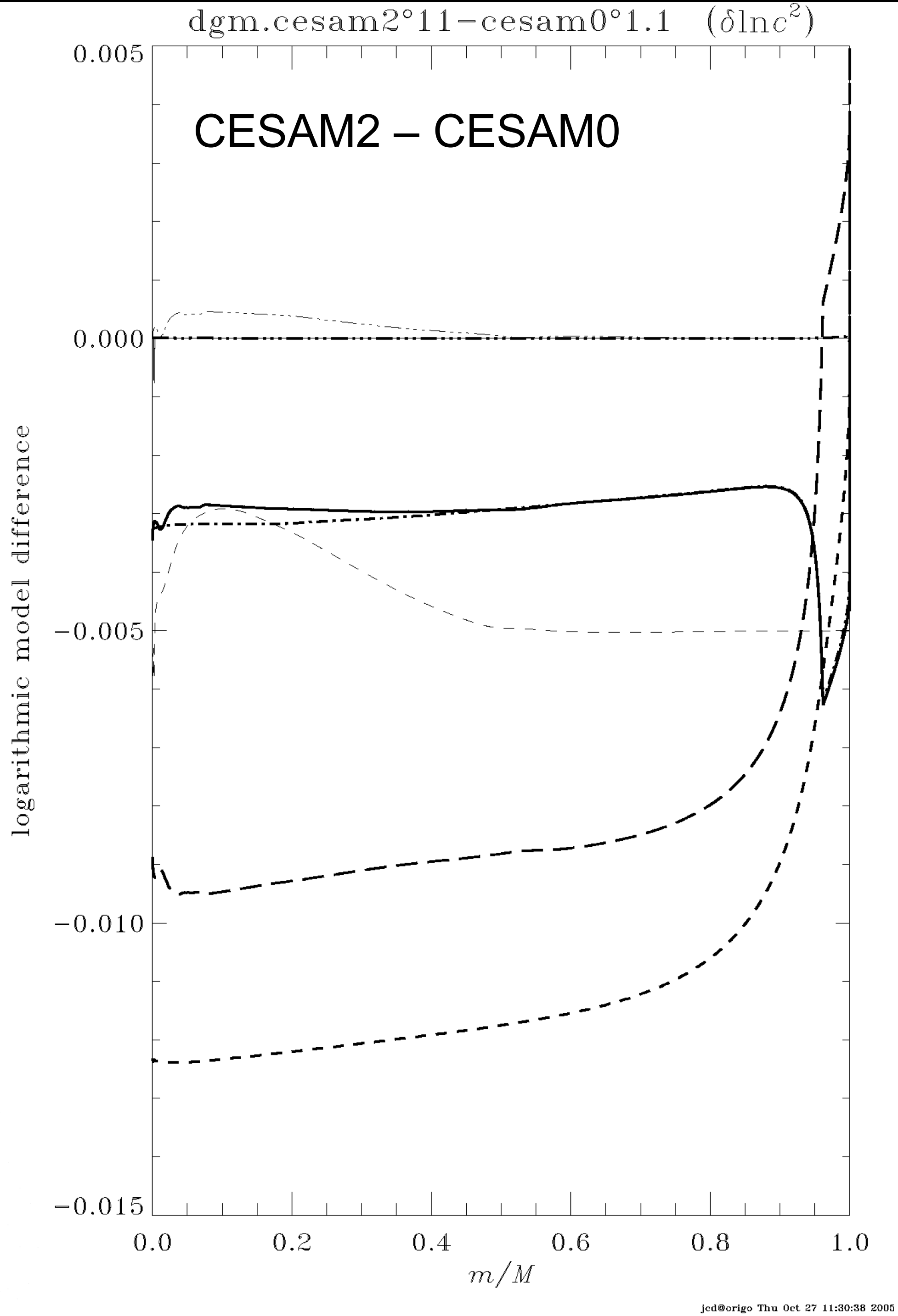
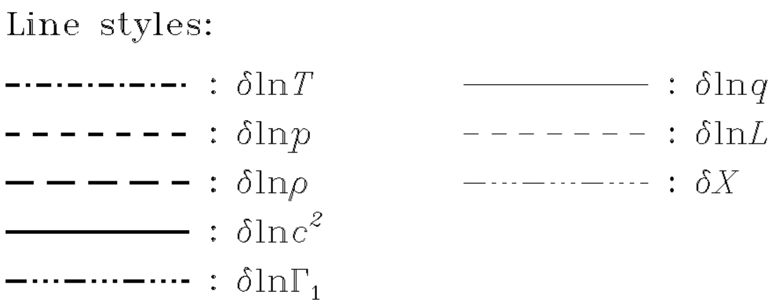
- short dash : $\delta \ln p$
- long dash : $\delta \ln \rho$
- solid : $\delta \ln c^2$
- dash-dot-dot : $\delta \ln \Gamma_1$
- thin solid : $\delta \ln q$
- thin dash : $\delta \ln L$
- thin dash-dot-dot : δX

Case 1.1

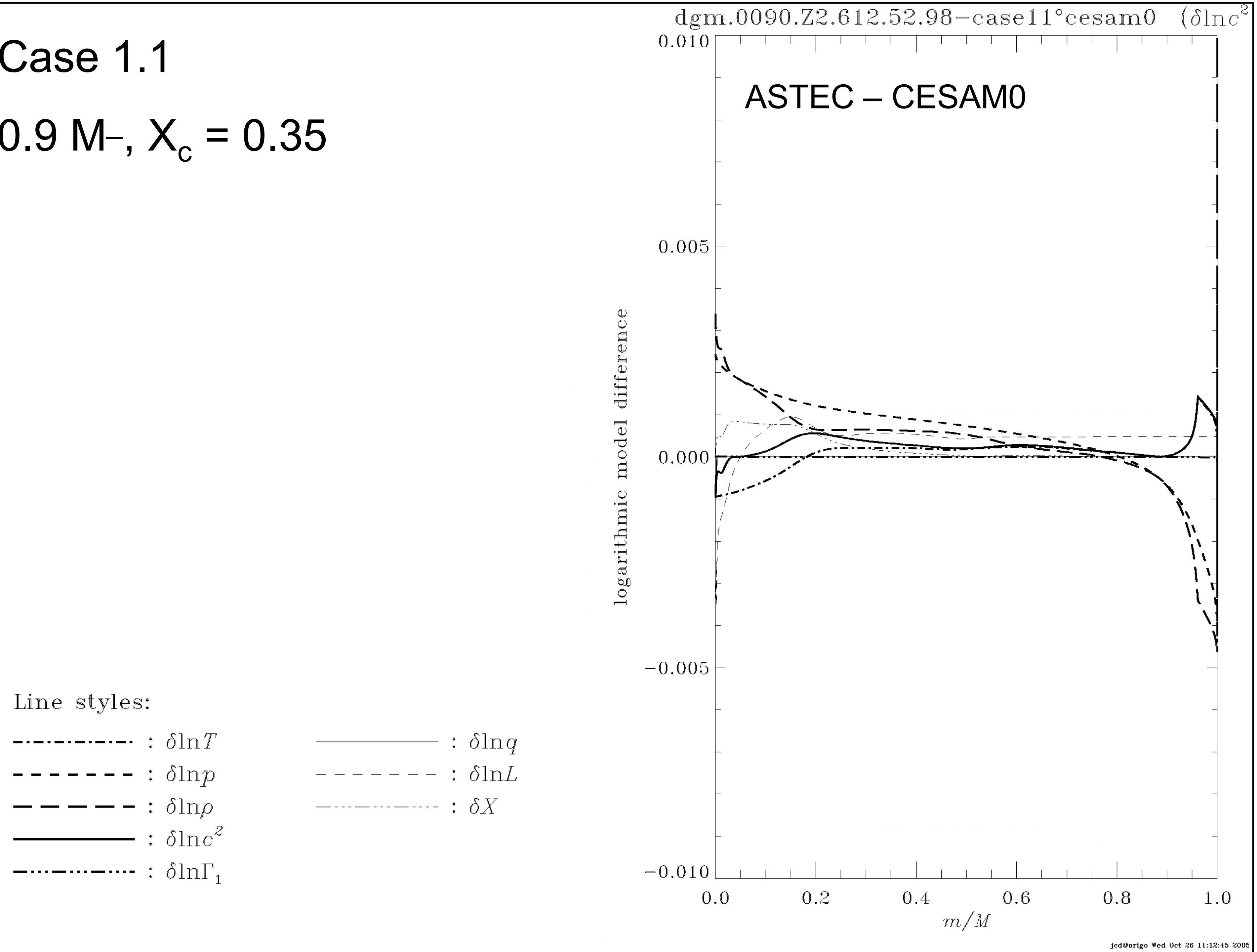
0.9 M–, X_c = 0.35





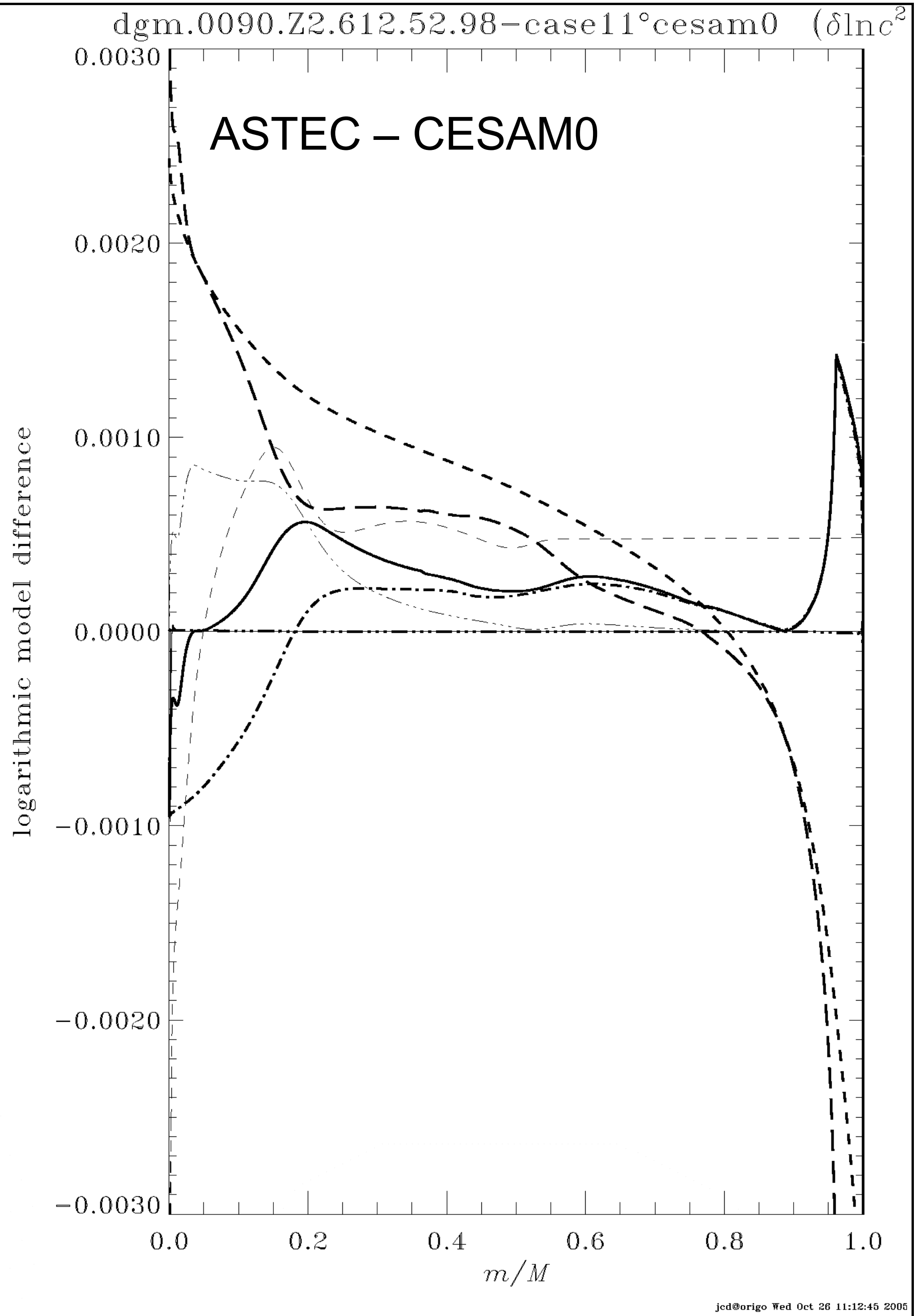
Case 1.1

0.9 M–, X_c = 0.35



Case 1.1

0.9 M⊙, X_c = 0.35

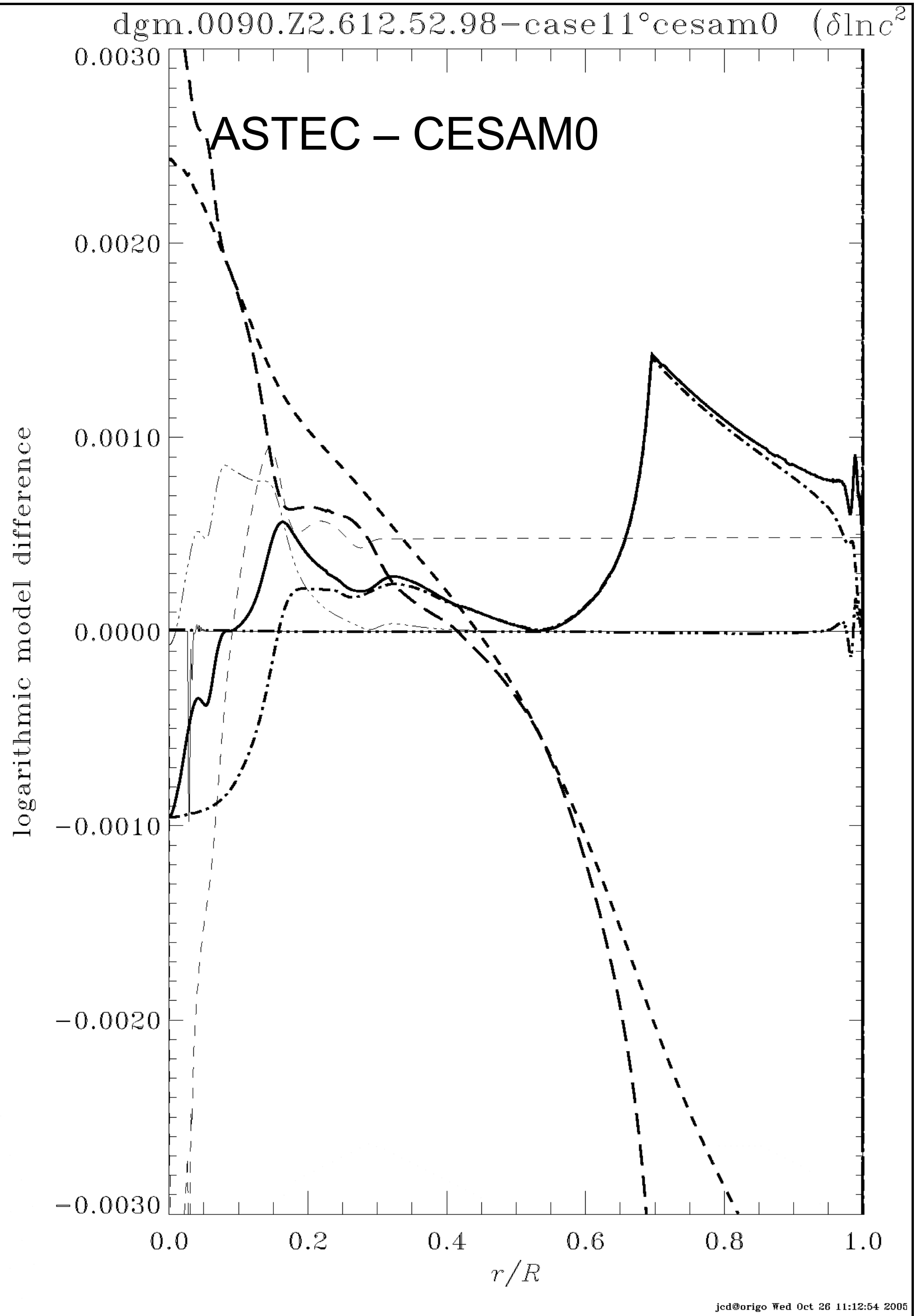


Line styles:

: $\delta \ln T$	: $\delta \ln q$
: $\delta \ln p$	: $\delta \ln L$
: $\delta \ln \rho$	: δX
: $\delta \ln c^2$	
: $\delta \ln \Gamma_1$	

Case 1.1

0.9 M–, X_c = 0.35

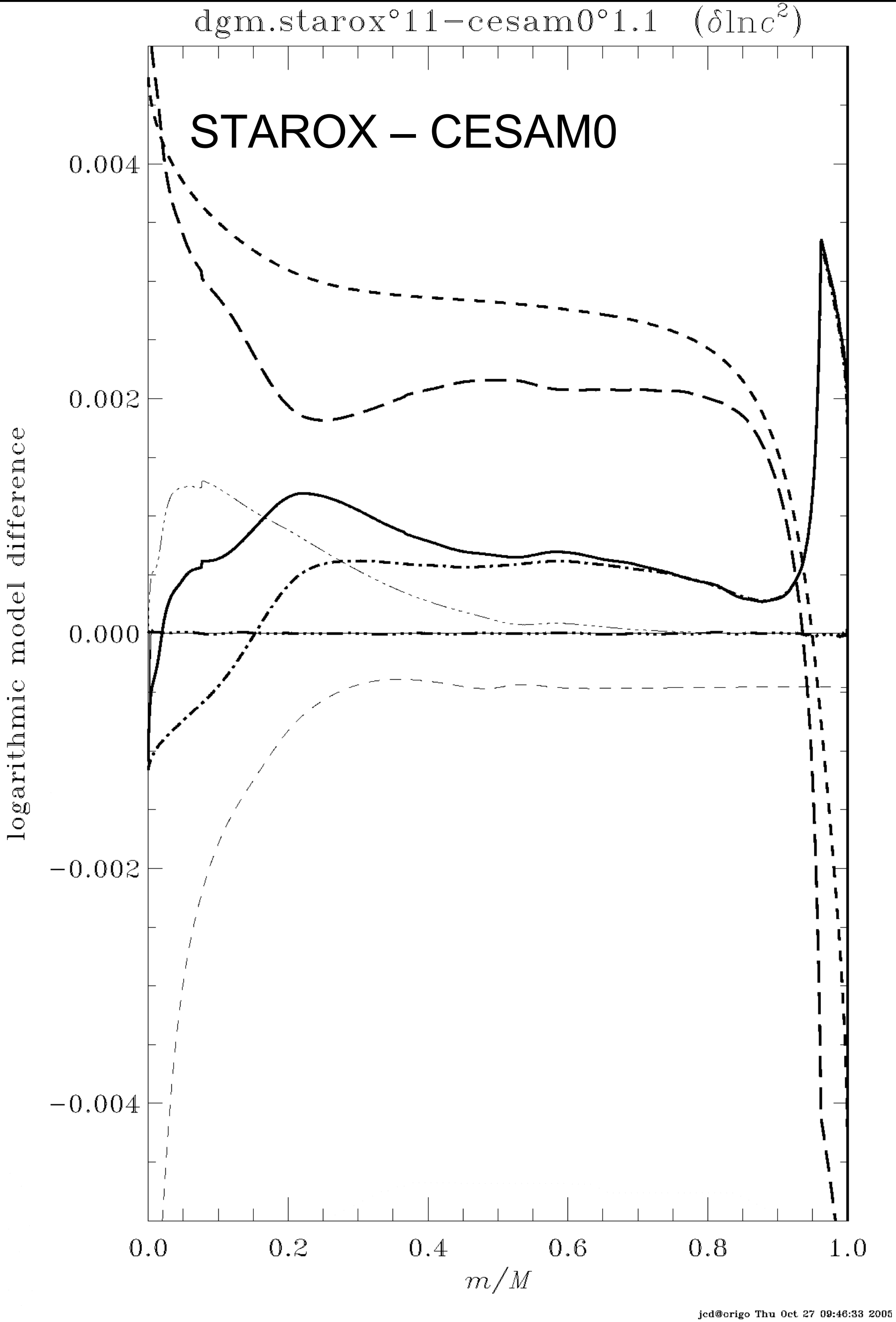


Line styles:

- $\delta \ln T$
- $\delta \ln p$
- $\delta \ln \rho$
- $\delta \ln c^2$
- $\delta \ln \Gamma_1$
- $\delta \ln q$
- $\delta \ln L$
- δX

Case 1.1

0.9 M–, X_c = 0.35



Line styles:

- dash-dot line : $\delta \ln T$
- short-dash line : $\delta \ln p$
- long-dash line : $\delta \ln \rho$
- thick solid line : $\delta \ln c^2$
- dash-dot-dot line : $\delta \ln \Gamma_1$
- thin solid line : $\delta \ln q$
- thin dashed line : $\delta \ln L$
- thin dash-dot-dot line : δX

Hydrogen abundance

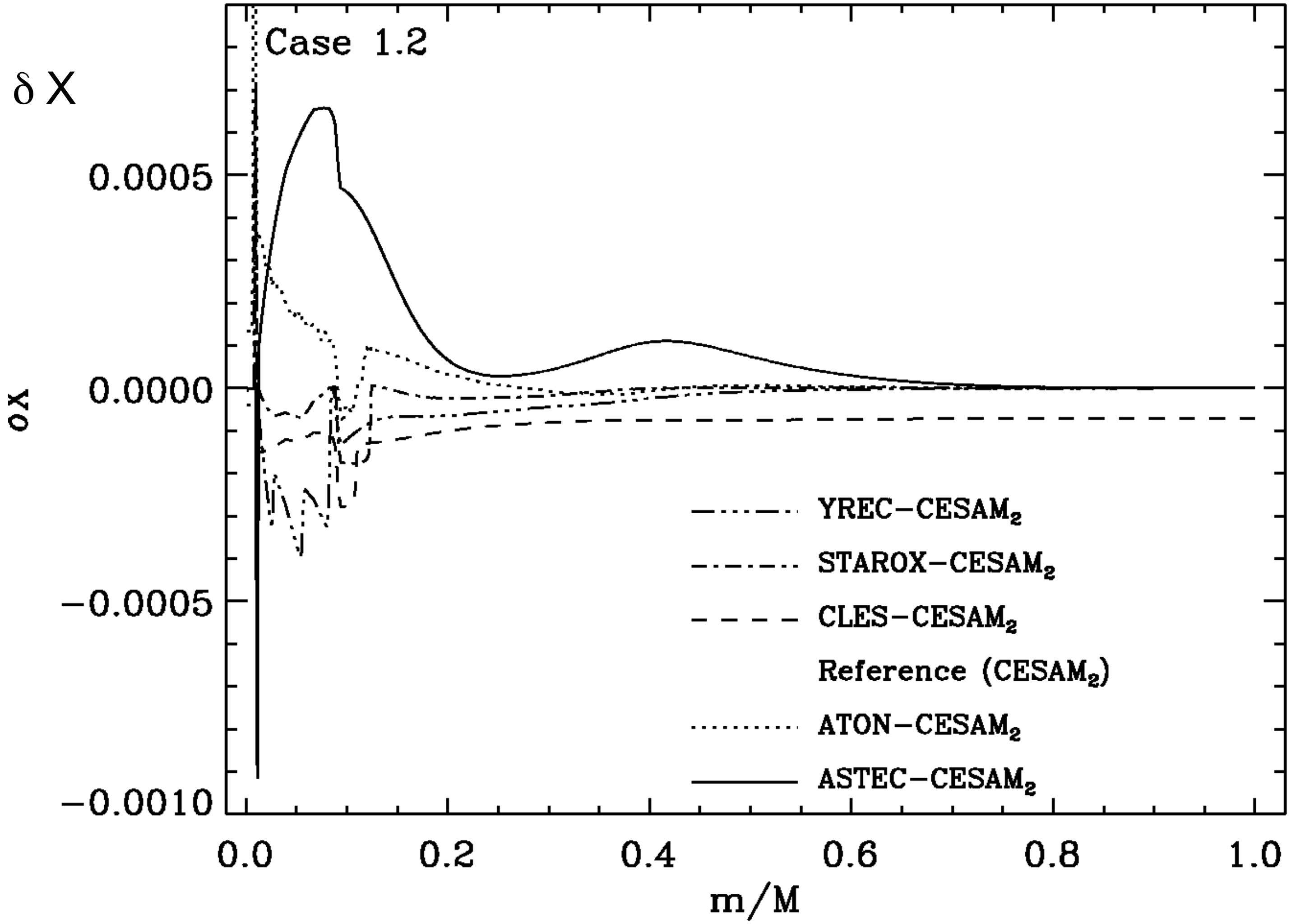
1.2 M⊙

$X_0 = 0.7$

$Z_0 = 0.02$

$X_c = 0.69$

δX



Case 1.2

1.2 M–

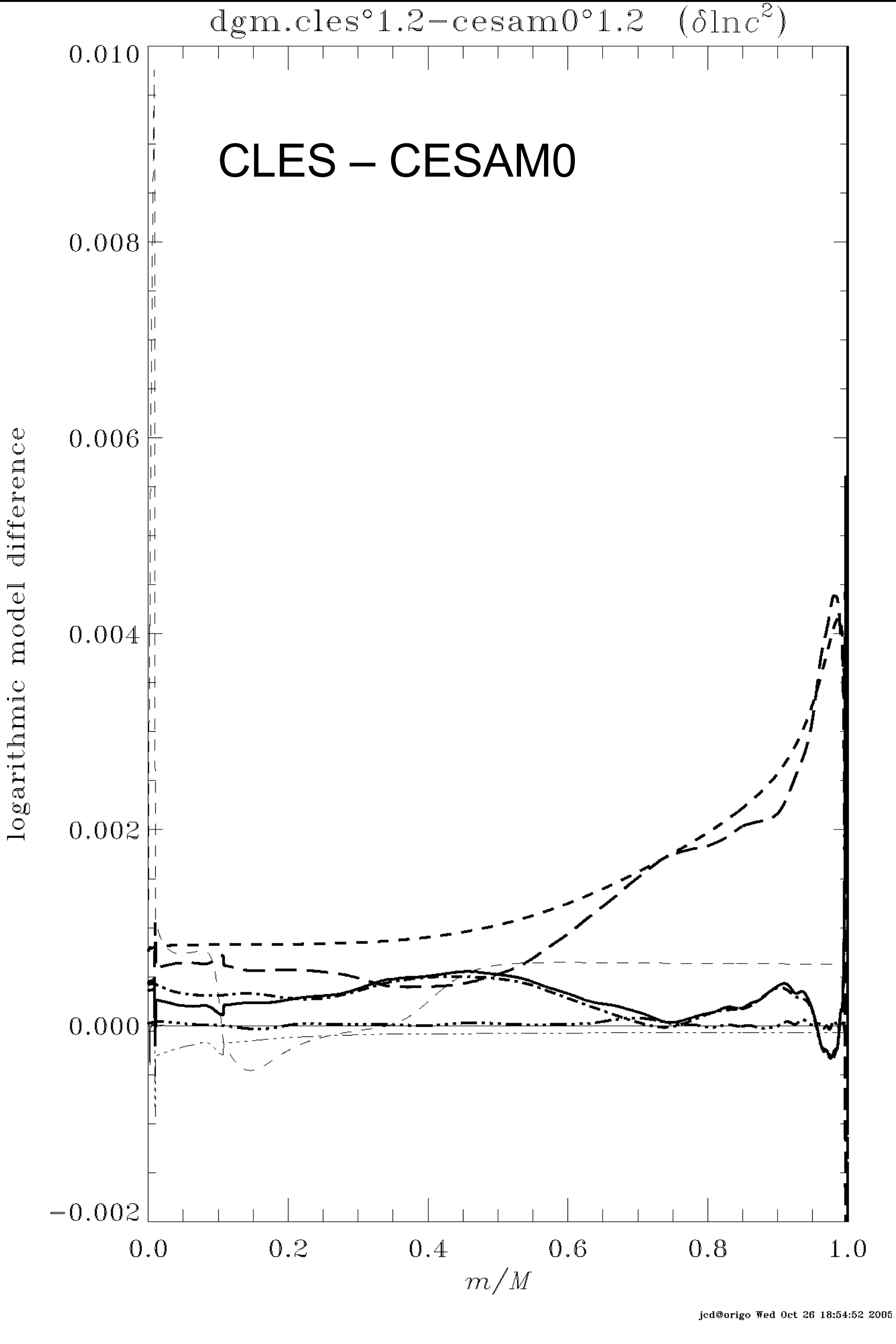
X_0 = 0.7

Z_0 = 0.02

X_c = 0.69

Line styles:

- –·–·–·– : $\delta\ln T$
- – – – – : $\delta\ln p$
- — — — : $\delta\ln\rho$
- ——— : $\delta\ln c^2$
- –···–··· : $\delta\ln\Gamma_1$
- ——— (thin) : $\delta\ln q$
- - - - - (thin) : $\delta\ln L$
- –···–··· (thin) : δX



Case 1.2

1.2 M–

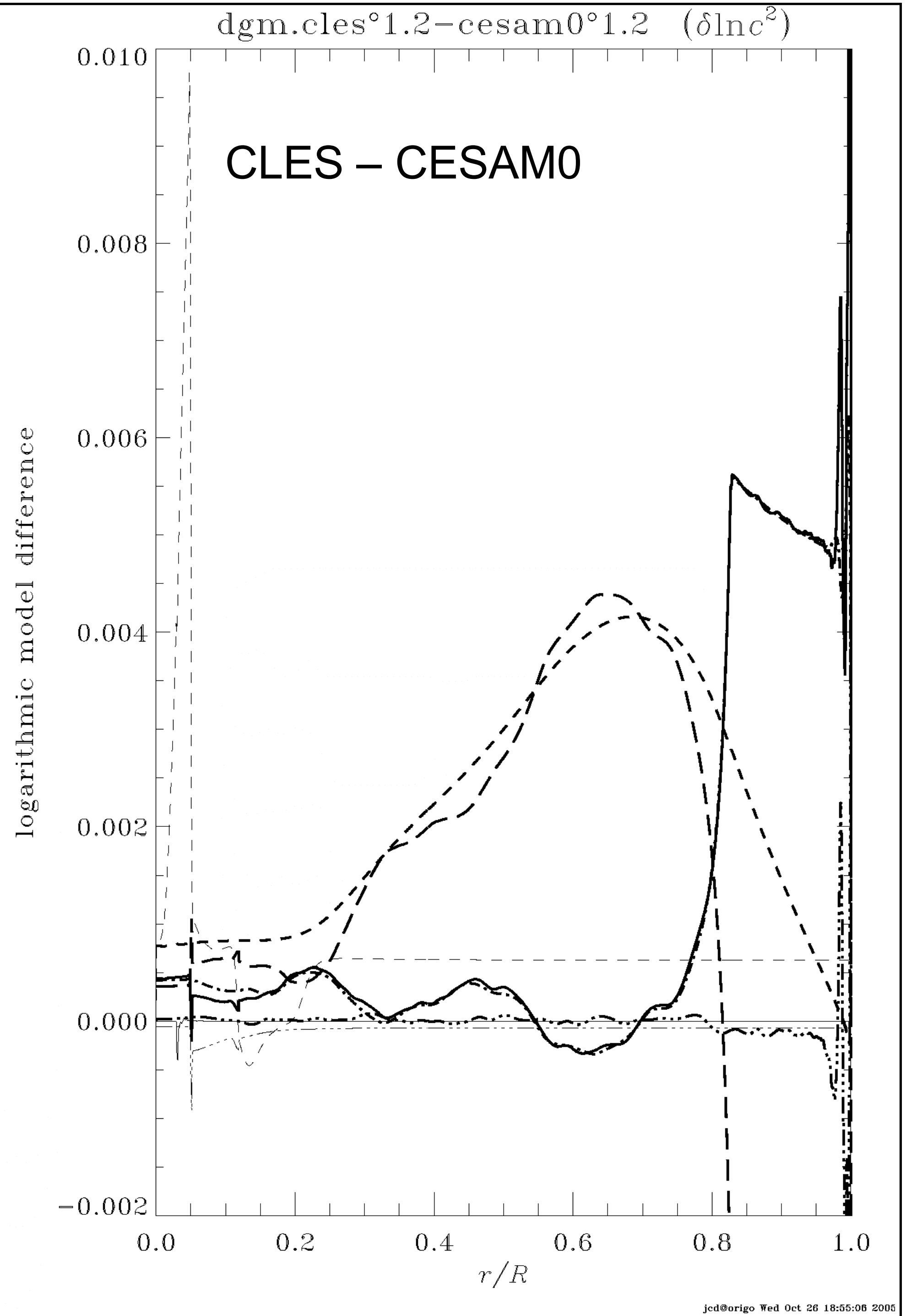
$X_0 = 0.7$

$Z_0 = 0.02$

$X_c = 0.69$

Line styles:

- dash-dot line : $\delta \ln T$
- short-dash line : $\delta \ln p$
- long-dash line : $\delta \ln \rho$
- solid line : $\delta \ln c^2$
- dash-dot-dot line : $\delta \ln \Gamma_1$
- thin solid line : $\delta \ln q$
- thin dashed line : $\delta \ln L$
- thin dash-dot-dot line : δX



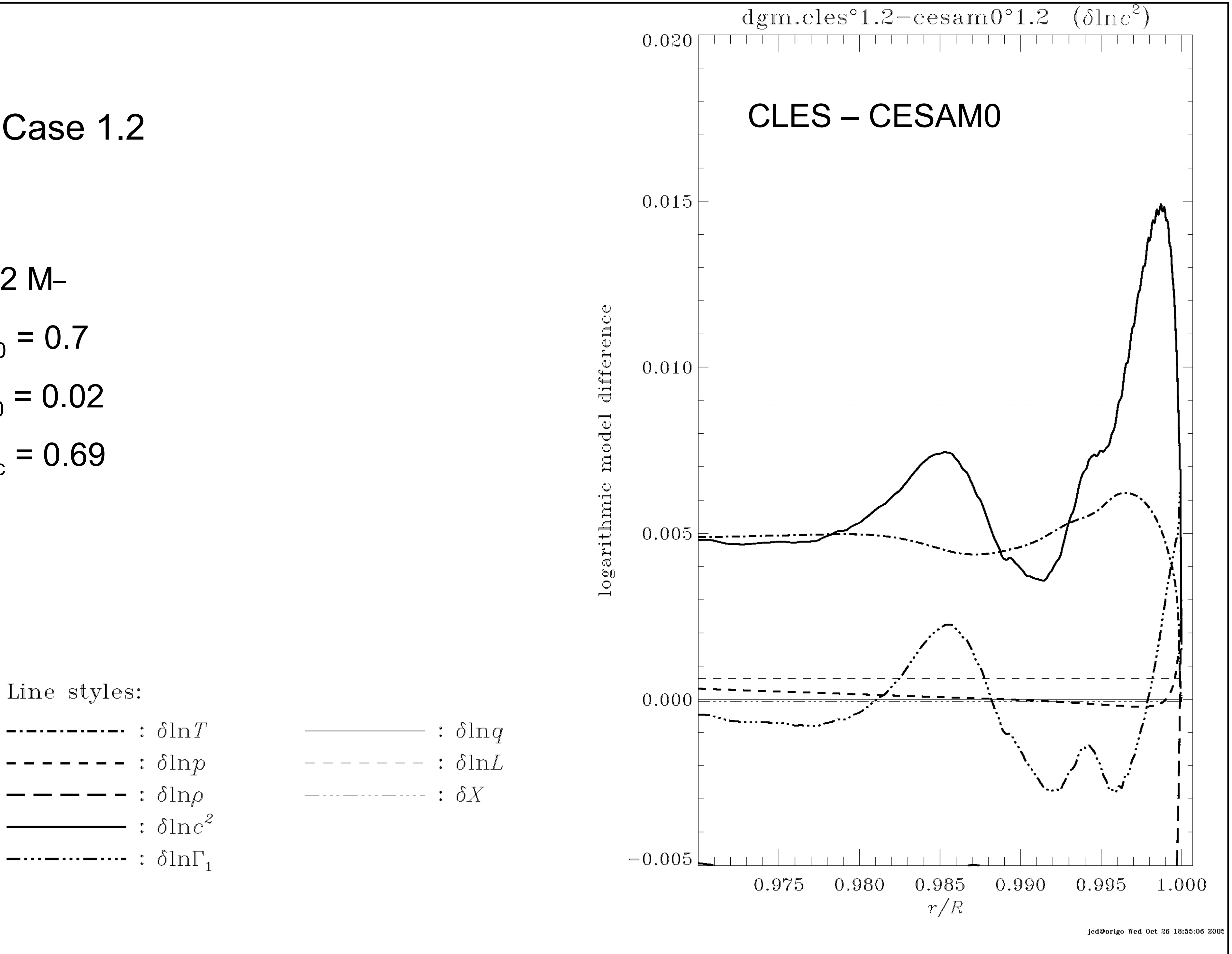
Case 1.2

1.2 $M_{\odot}$

$X_0 = 0.7$

$Z_0 = 0.02$

$X_c = 0.69$



Case 1.2

1.2 M–

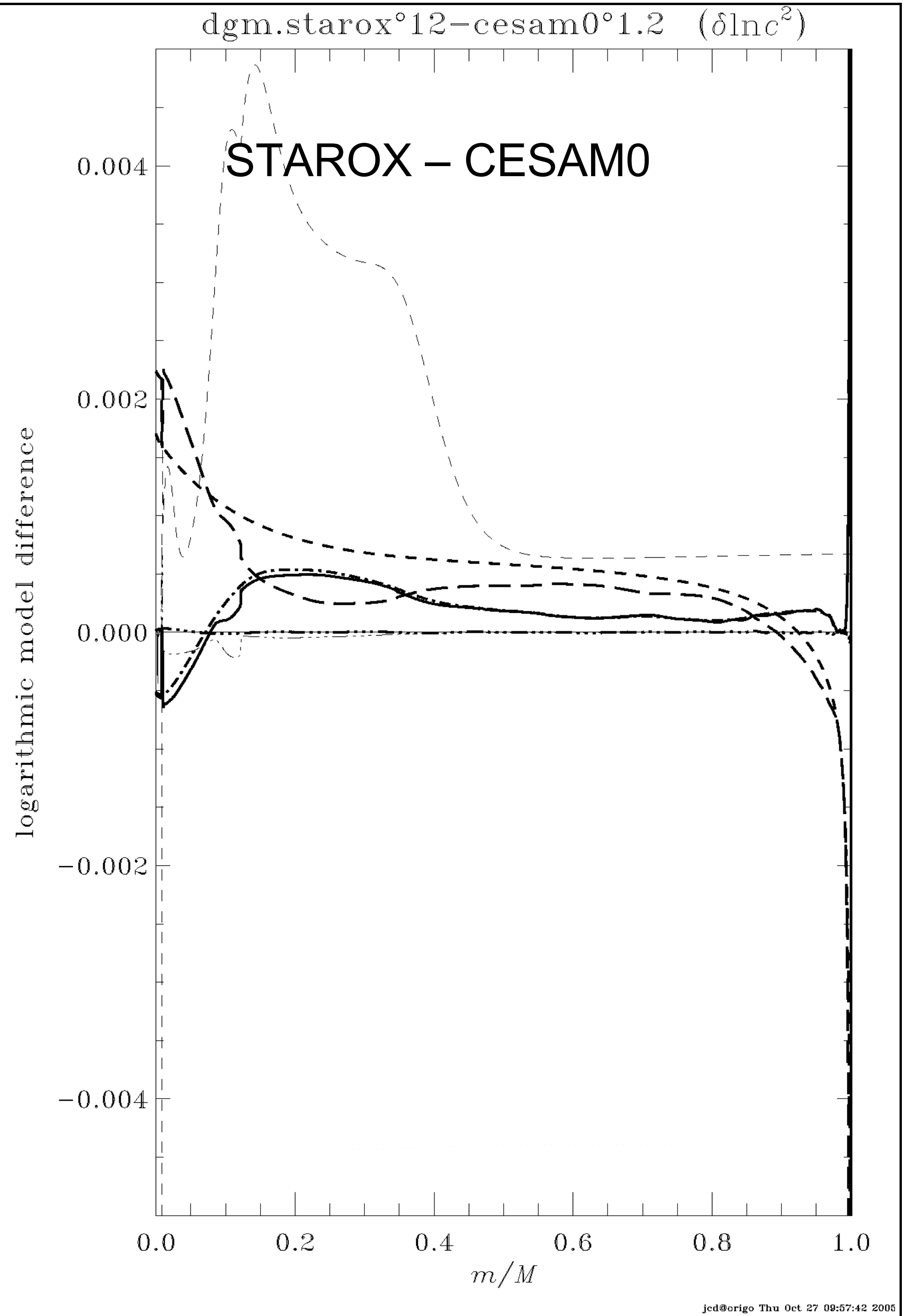
X_0 = 0.7

Z_0 = 0.02

X_c = 0.69

Line styles:

- –·–·–·– : $\delta \ln T$
- – – – – : $\delta \ln p$
- — — — : $\delta \ln \rho$
- ——— : $\delta \ln c^2$
- –···–···– : $\delta \ln \Gamma_1$
- ——— (thin) : $\delta \ln q$
- - - - - (thin) : $\delta \ln L$
- –···–··· (thin) : δX



Case 1.2

1.2 M–

X_0 = 0.7

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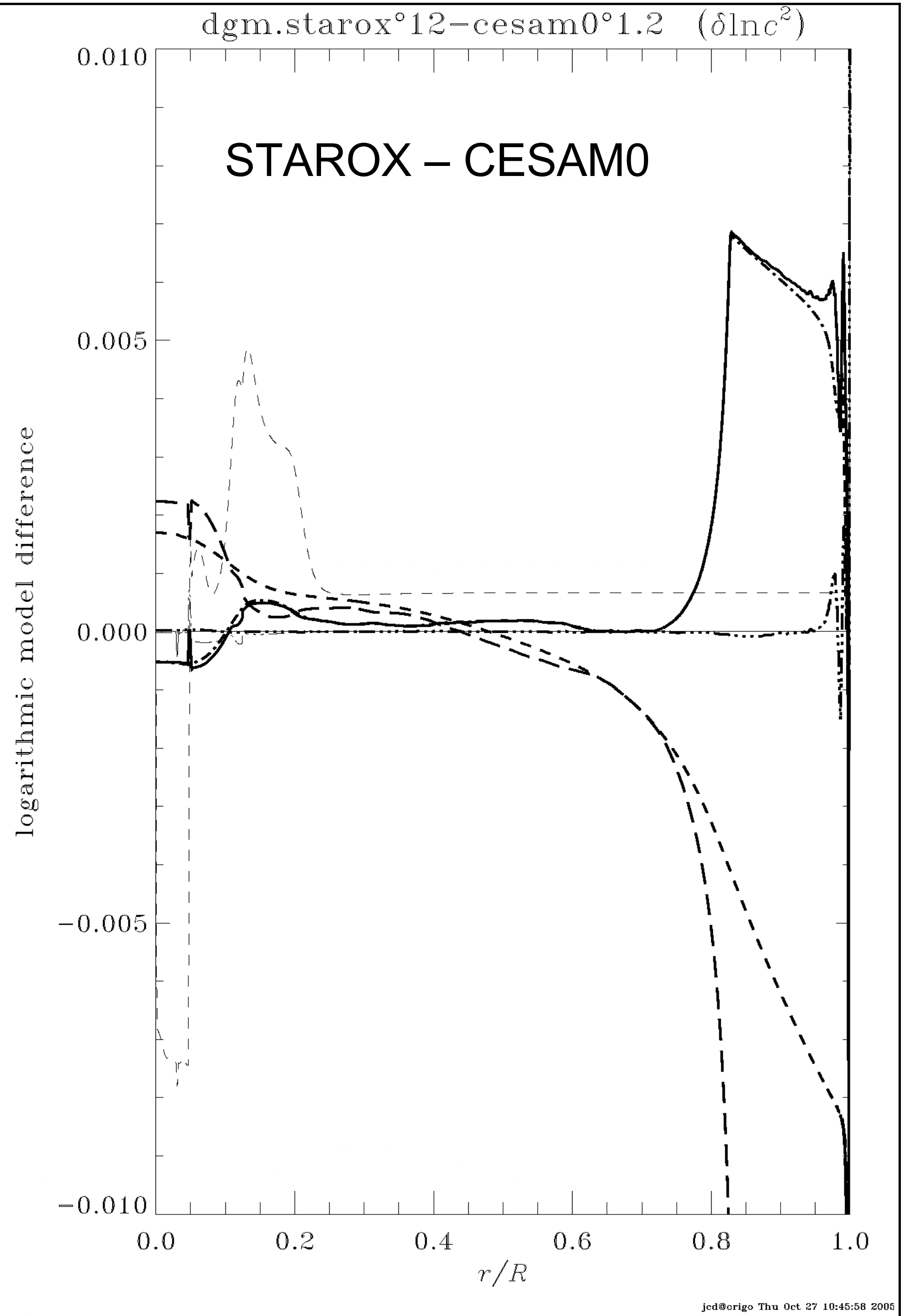
X_c = 0.69

Line styles:

- -·-·-·- : $\delta \ln T$
- - - - - : $\delta \ln p$
- — — — : $\delta \ln \rho$
- —— : $\delta \ln c^2$
- -···- : $\delta \ln \Gamma_1$
- —— (thin) : $\delta \ln q$
- - - - (thin) : $\delta \ln L$
- -··- (thin) : δX



Near-surface problems

- Differences in atmospheric treatment?
- Differences in mixing-length treatment?
- Results in different radii!

Action: compare details of mixing-length formulations

Hydrogen abundance

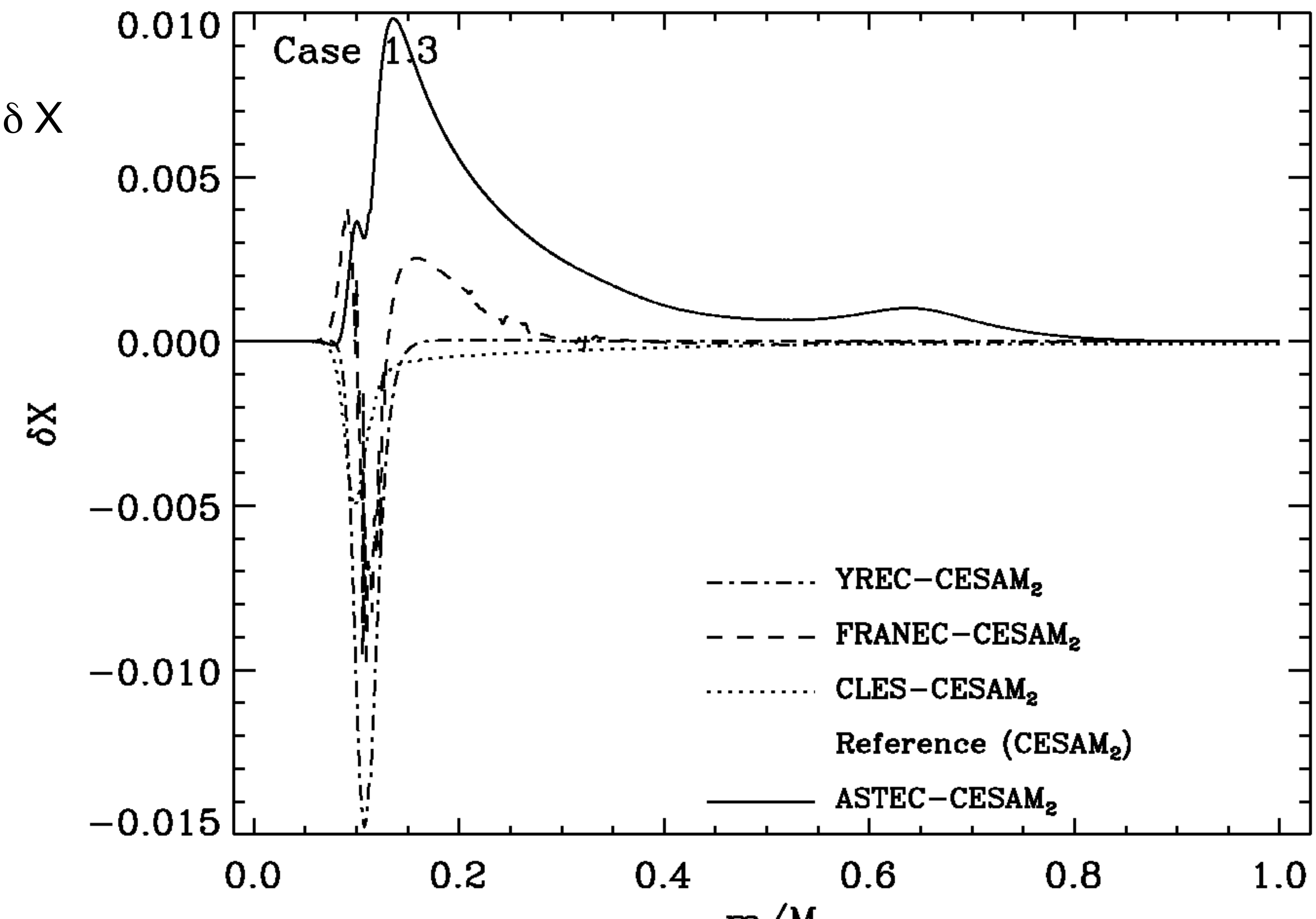
1.2 M–

$X_0 = 0.73$

$Z_0 = 0.01$

$M_{HeC}/M = 0.1$

δ X



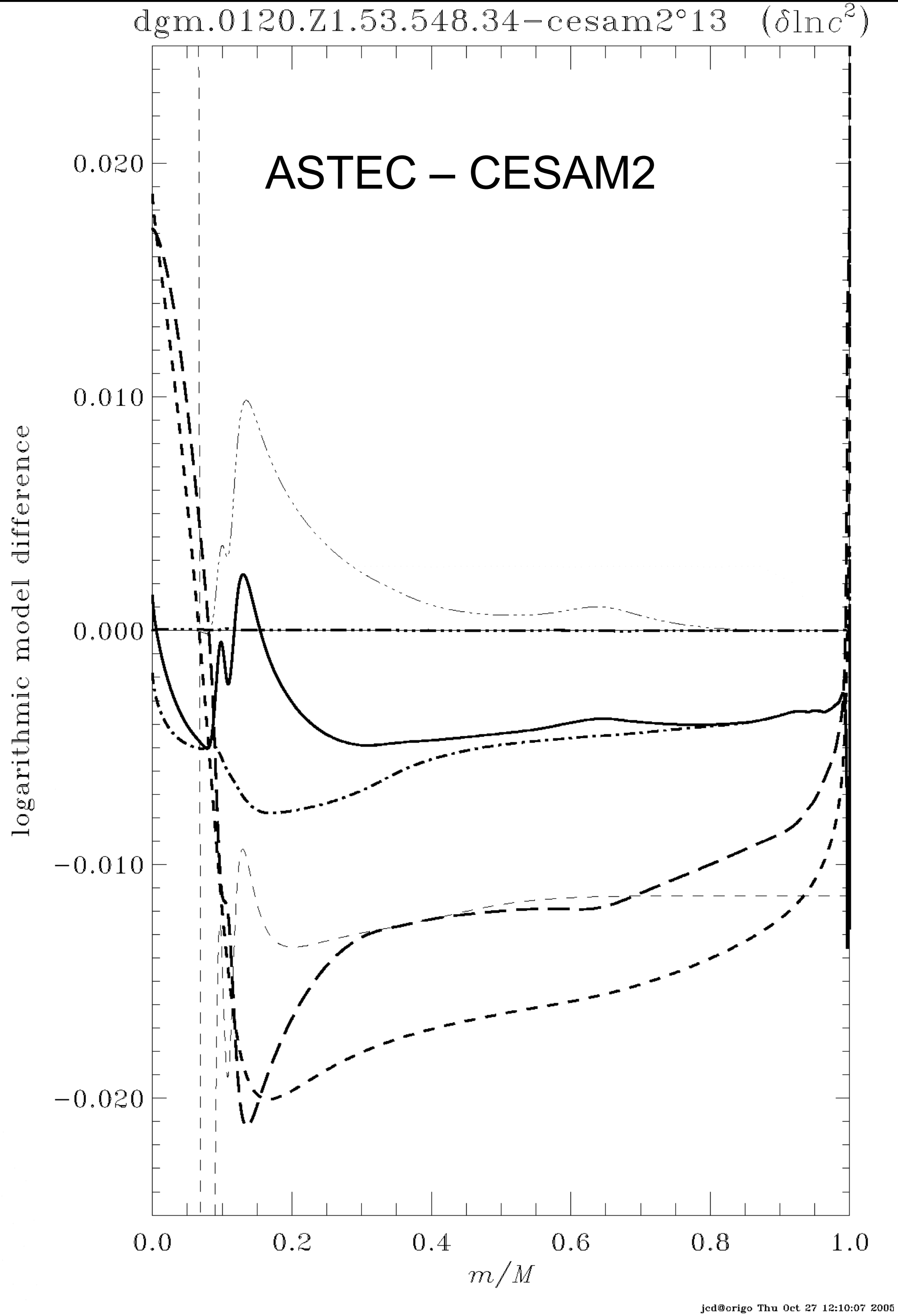
Case 1.3

1.2 M⊙

X_0 = 0.73

Z_0 = 0.01

M_{HeC}/M = 0.1



Line styles:

- : $\delta\ln T$
- : $\delta\ln p$
- : $\delta\ln\rho$
- : $\delta\ln c^2$
- : $\delta\ln\Gamma_1$
- : $\delta\ln q$
- : $\delta\ln L$
- : δX

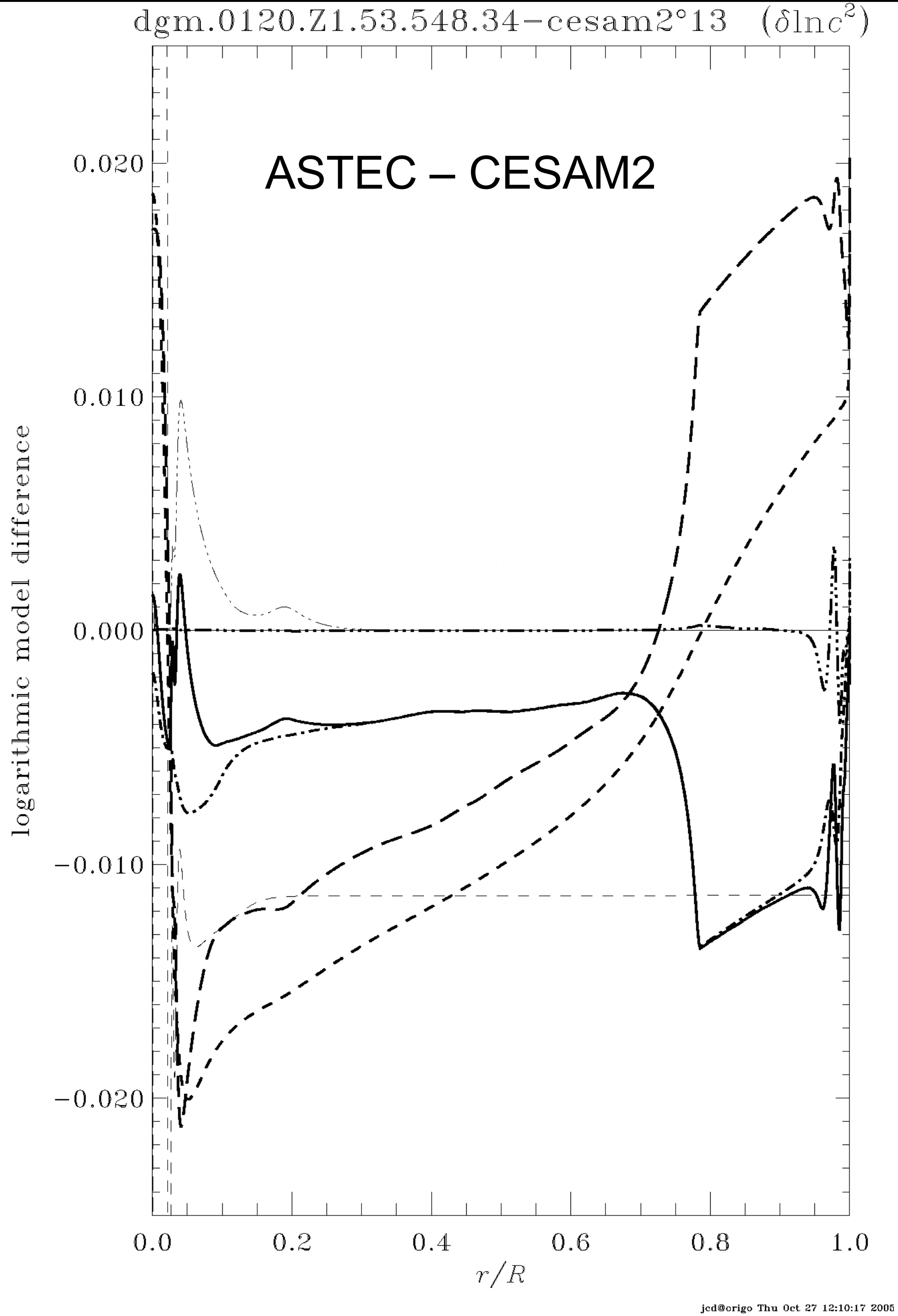
Case 1.3

1.2 M–

X_0 = 0.73

Z_0 = 0.01

M_{HeC}/M = 0.1



Line styles:

- ‑·‑·‑·‑·‑ : $\delta \ln T$
- ‑ ‑ ‑ ‑ ‑ : $\delta \ln p$
- — — — : $\delta \ln \rho$
- ——— : $\delta \ln c^2$
- ‑···‑···‑ : $\delta \ln \Gamma_1$
- ——— (thin) : $\delta \ln q$
- ‑ ‑ ‑ (thin) : $\delta \ln L$
- ‑···‑··· (thin) : δX

Hydrogen abundance

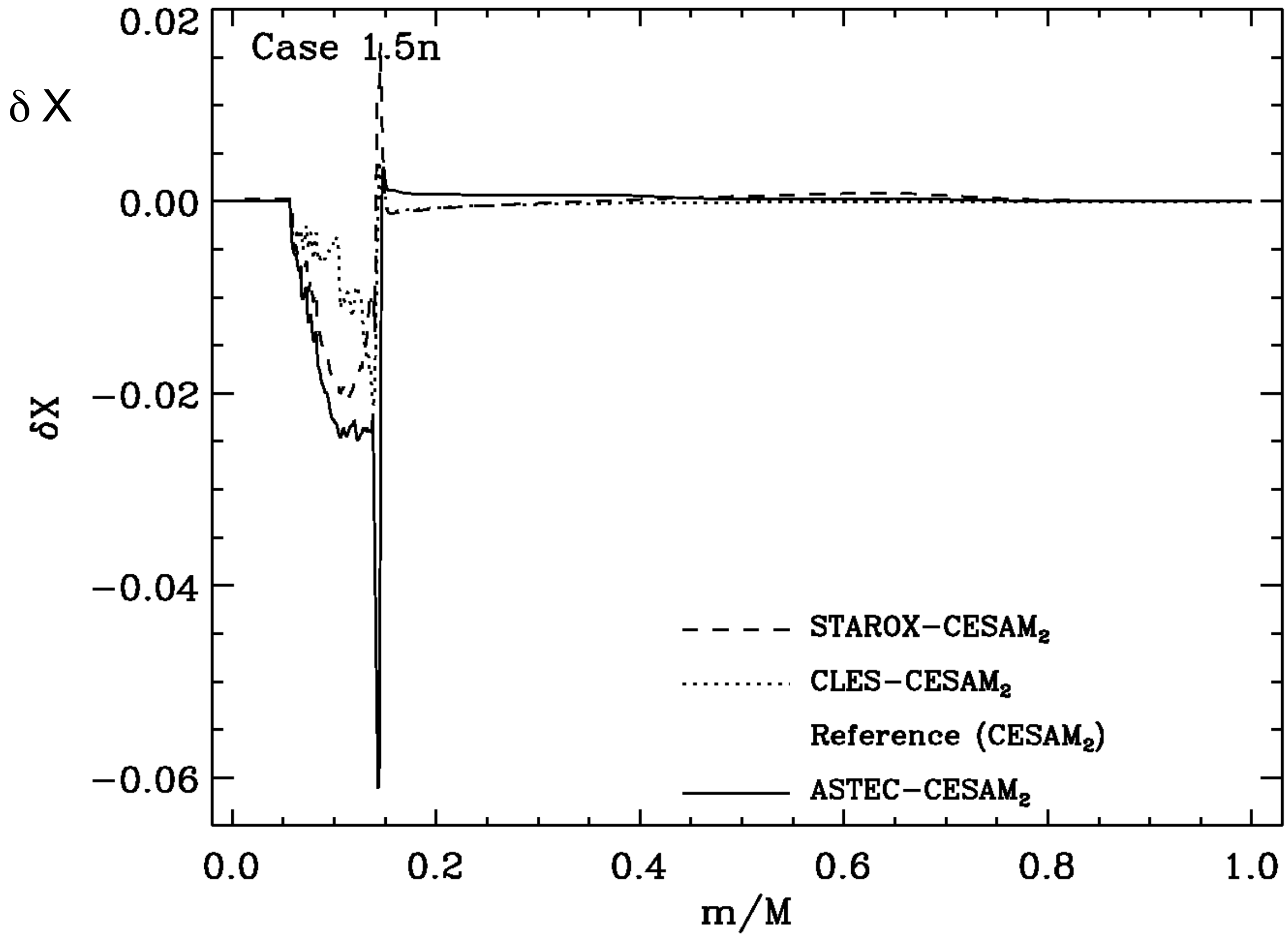
2.0 M–

X_0 = 0.72

Z_0 = 0.02

X_c = 0.01

No overshoot



Case 1.5n

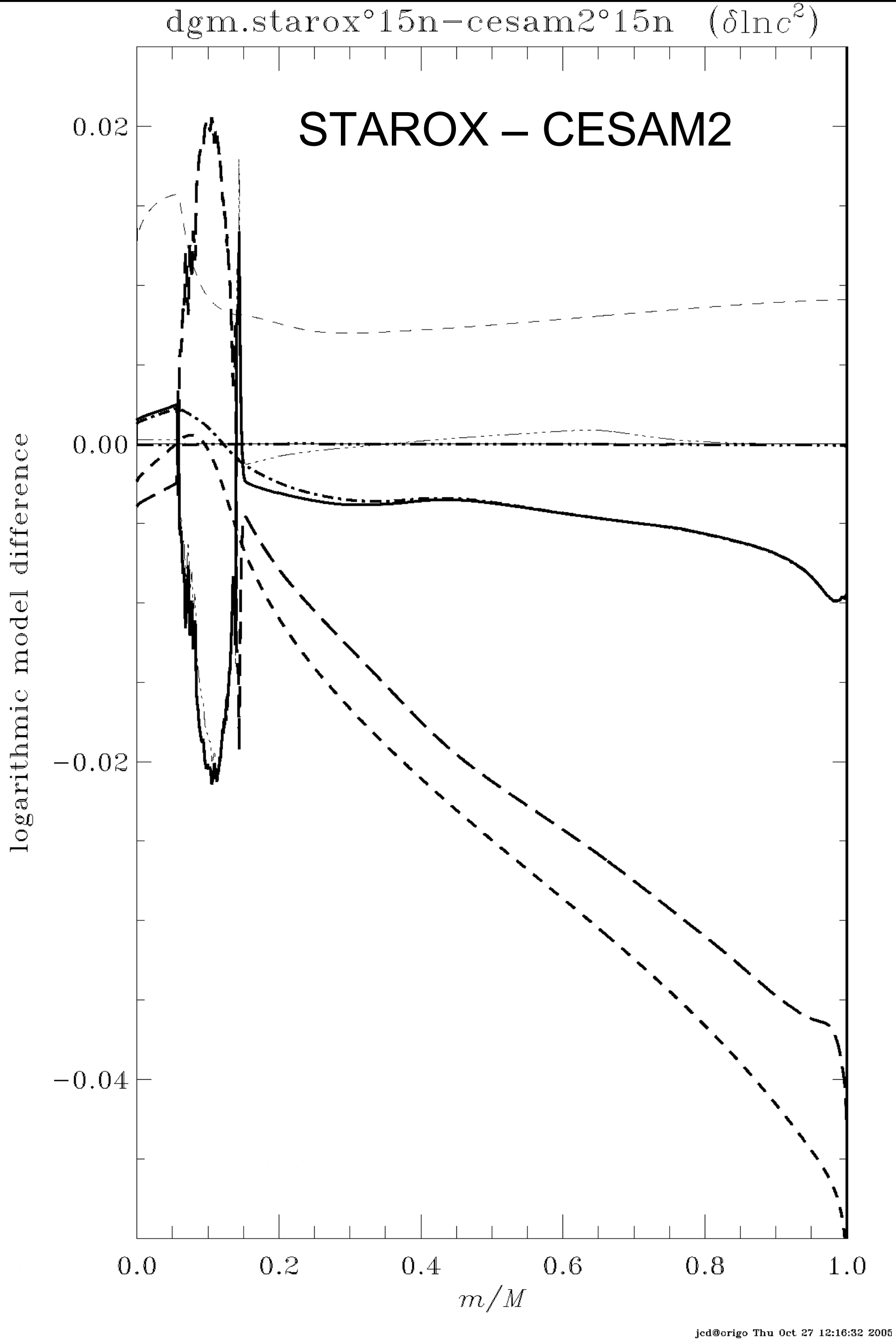
2.0 M–

X_0 = 0.72

Z_0 = 0.02

X_c = 0.01

No overshoot



Line styles:

- dash-dot : $\delta \ln T$
- short dash : $\delta \ln p$
- long dash : $\delta \ln \rho$
- solid : $\delta \ln c^2$
- dash-dot-dot : $\delta \ln \Gamma_1$
- thin solid : $\delta \ln q$
- thin dashed : $\delta \ln L$
- thin dash-dot-dot : δX

Case 1.5n

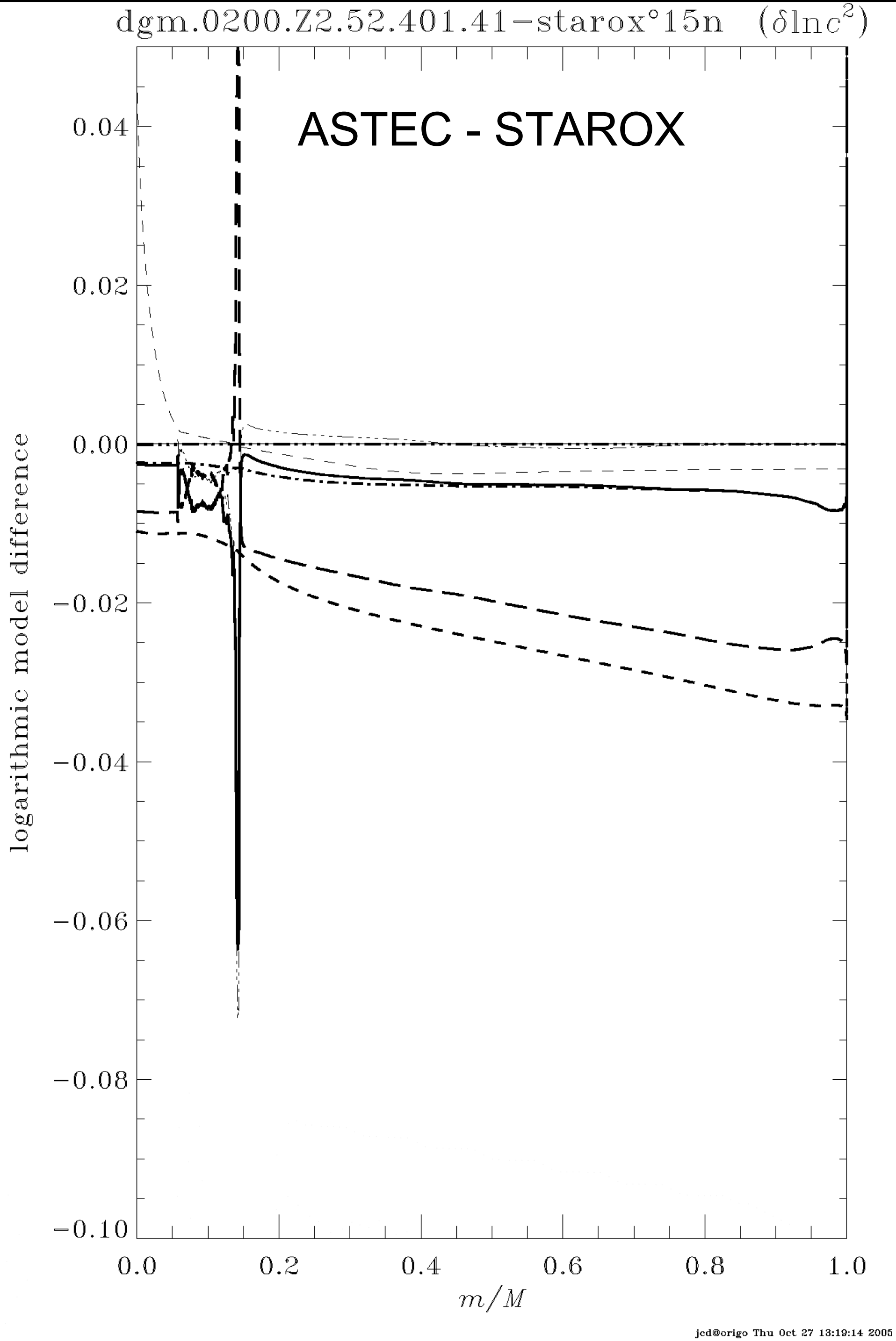
2.0 M–

X_0 = 0.72

Z_0 = 0.02

X_c = 0.01

No overshoot



Line styles:

- dash-dot : $\delta \ln T$
- short dashes : $\delta \ln p$
- long dashes : $\delta \ln \rho$
- thick solid : $\delta \ln c^2$
- dash-triple-dot : $\delta \ln \Gamma_1$
- thin solid : $\delta \ln q$
- thin dashes : $\delta \ln L$
- thin dash-dot-dot : δX

Hydrogen abundance

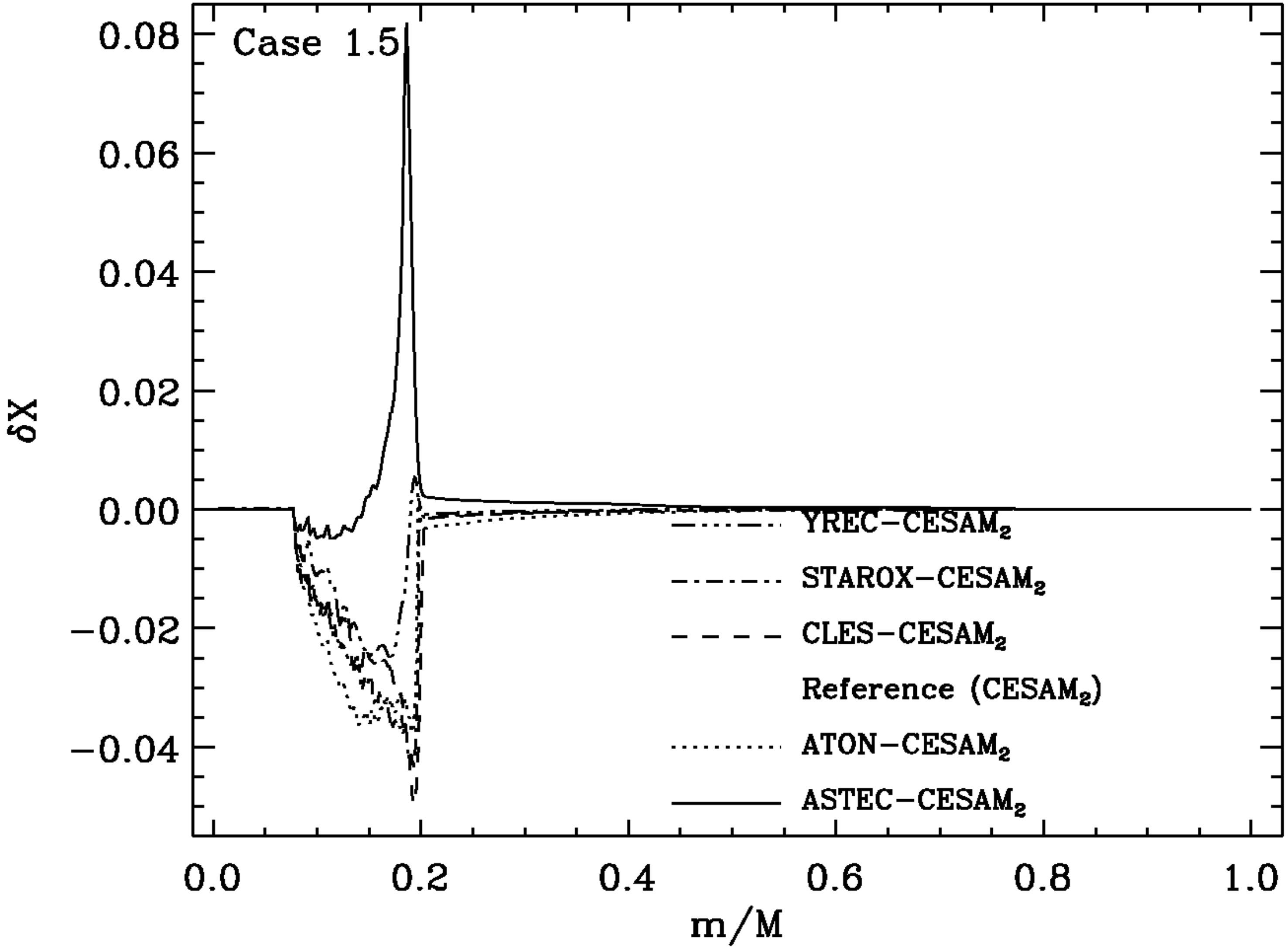
2.0 M⊙

$X_0 = 0.72$

$Z_0 = 0.02$

$X_c = 0.01$

Overshoot, 0.15 H_p



Case 1.5

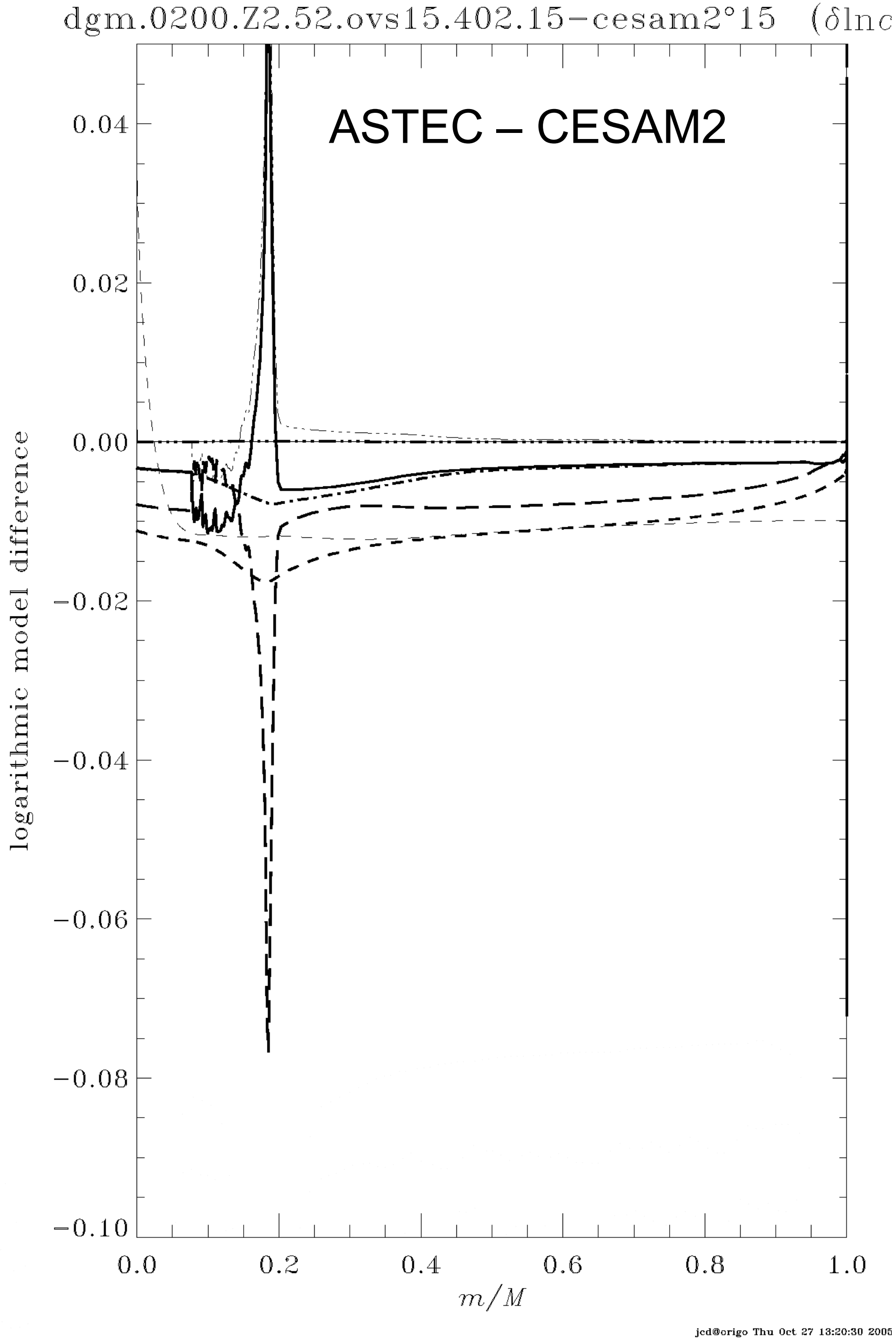
2.0 M–

X_0 = 0.72

Z_0 = 0.02

X_c = 0.01

Overshoot
0.15 H_p



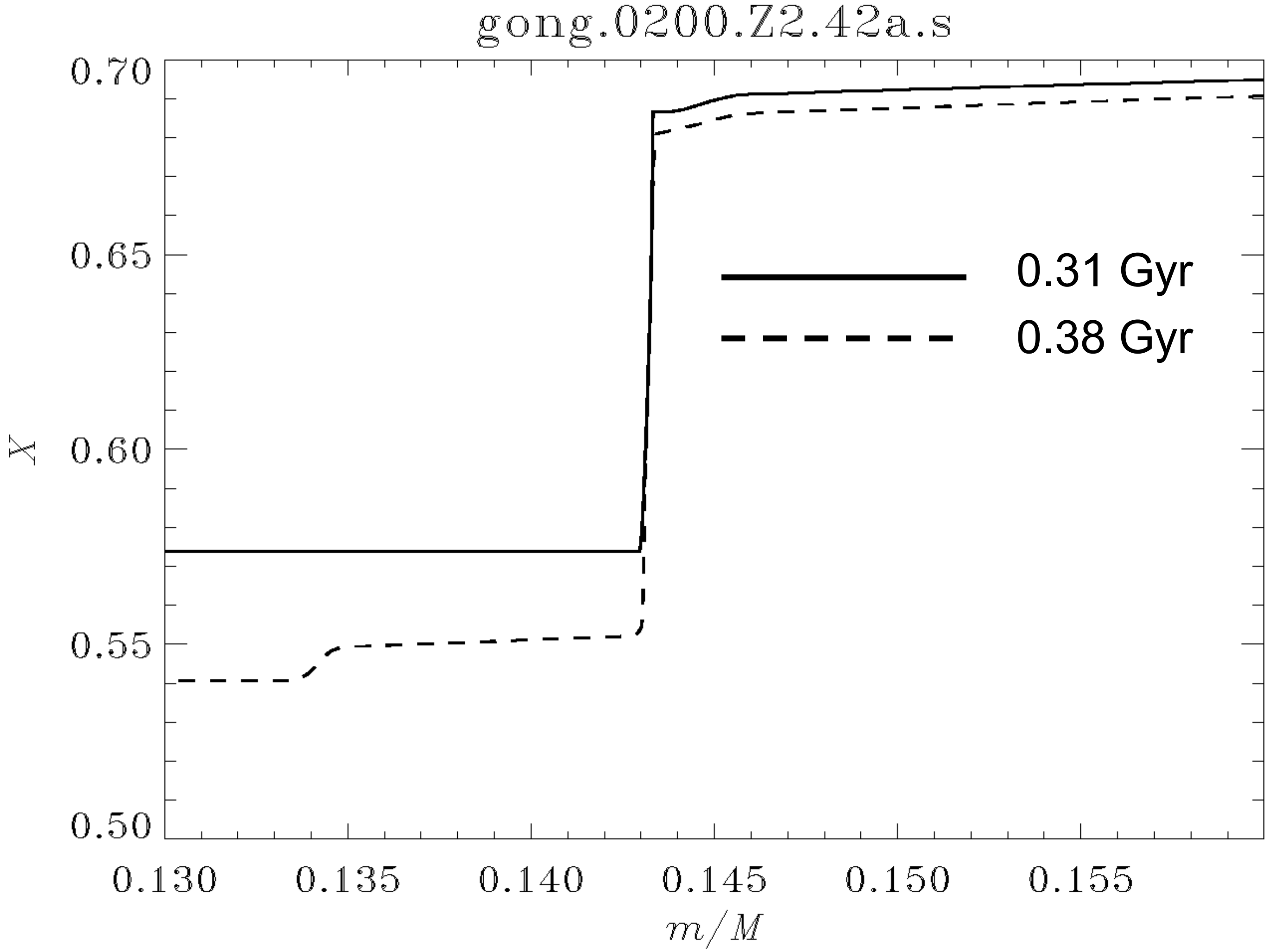
Line styles:

- · - · - · - · - · : $\delta\ln T$
- - - - - - - : $\delta\ln p$
— — — — : $\delta\ln\rho$
———— : $\delta\ln c^2$
— · · · — · · · : $\delta\ln\Gamma_1$
———— (thin) : $\delta\ln q$
- - - - - - - (thin) : $\delta\ln L$
— · · · — · · · (thin) : δX

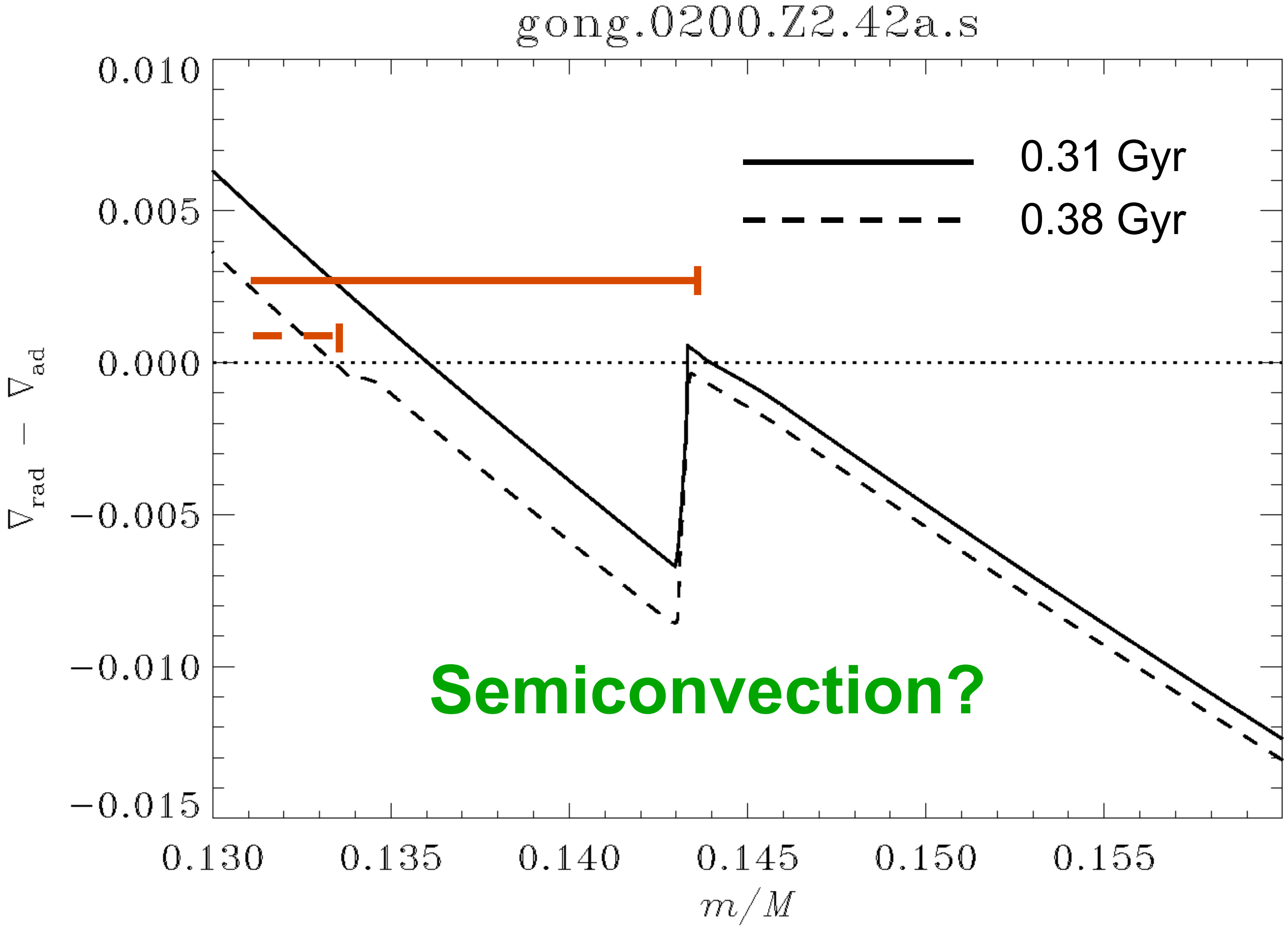
Problems with growing convective core

2 M⊙

Z = 0.02



Problems with growing convective core



Semiconvection