CoRoT/ESTA - Model Comparison - Task 1

Global parameters and evolutionary sequences

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Abstract

In this work we present the results on the global parameters and evolutionary sequences for Task 1 of the *Evolution and Seismic Tools Activity* (ESTA) of the CoRoT *Seismology Working Group*. For this Task several target stars have been defined. Models produced with different evolution codes have then been calculated to represent these target stars and the results are compared.

A list of the Codes being used to calculate the models and the summary of the reference physics adopted in the comparison are presented. A brief description of the targets proposed is given. The global parameters and the evolutionary sequences in the HR Diagram are compared in order to identify and quantify the major differences between the codes being used. The work reported here is complemented by another poster on the comparison of the internal structure and seismic characteristics of the targets.

1 Evolution Codes

The Evolution codes used in this comparison are listed here with the references where the description of each code can be found. The results presented in the next sections have been calculated by the following codes:

- **ASTEC - Aarhus Stellar Evolution Code** [*Christensen-Dalsgaard*] - a general description of the code available in print is Christensen-Dalsgaard (1982). Further up-to-date details can also be found in Christensen-Dalsgaard (2005a).

- **CESAM - Code d'Évolution Stellaire Adaptatif et Modulaire** [*Lebreton & Morel*] - a published general description in english of the code available in print is Morel (1997). A detailed description (in french) is available under request at the WEB sites:
  `http://www.obs-nice.fr/morel/CESAM`
  `http://www.obs-nice.fr/cesam/`
  An up-to-date description can also be found at Pichon & Morel (2005).

- **CLES - Code Liègeois d'Evolution Stellaire** [*Montalbán, Scuflaire & BAG*] - CLES is still in an active phase of development at the Institute of Astrophysics of Liège. Further up-to-date details can be found in Scuflaire (2005).
- **FRANEC - Pisa Evolution Code** [*Degl'Innocenti, Marconi & Prada Moroni*] - The main properties and physical assumptions of the FRANEC code are discussed in Cariulo et al. (2004) (see also Ciacio et al. 1997). Further up-to-date details can also be found in Degl'Innocenti & Marconi (2005).
- **GENEC - Geneva Evolution Code** [*Eggenberger*] - The main properties and physical assumptions of the GENEC code are discussed in ???.
- **STAROX - Roxburgh's Evolution Code** [*Roxburgh*] - A description of the main properties and physical assumptions of the code can be found in Roxburgh (2005).
- **TGEC - Toulouse-Geneva Evolution Code** [*Castro*] - The details of the code are described in Charbonnel et al. (1992) and Richard et al. (1996). Further up-to-date details can also be found in Castro (2005).

2 Target stars for Task 1

Seven targets have been defined. They have been selected to cover a representative range in stellar masses and ages. One case has also been considered for the presence of overshoot. The reference set of physics proposed for the comparison was:

- **Equation of State** - OPAL by Rogers et al. (1996, 2001 Tables);
- **Opacities** - OPAL by Iglesias & Rogers (1996) + Alexander & Ferguson (1994);
- **Reaction rates** - analytical fits of NACRE by Angulo et al. (1999);
- **Convection** - MLT by Böhm-Vitense (1958), as calibrated by Henyey et al. (1965) with,

$$\alpha \equiv \frac{\ell_{\rm MLT}}{H_p} = 1.6 \ ;$$

- **Overshoot** - fully mixed and $\nabla = \nabla_{\rm a}$ with,

$$\alpha_{\rm ov} \equiv \frac{\ell_{\rm ov}}{H_p} \ ;$$

- **Mixture** - solar as given by Grevesse & Noels (1993);
- **Atmosphere** - grey Eddington atmosphere.

A more detailed description of the physics can also be found at:
`http://www.astro.up.pt/corot/compmod/docs/Task1_Roadmap.pdf`

These are not necessarily the latest up-to-date specifications, but have been selected in order to form a "standard" set of physics.

The parameters for the evolution that have been specified for each case are listed in Table 1. These are represented in Fig. (1). The specifications given here assume the following definition:

- $M_{\rm HeC}$ is the mass of the central region of the star where the hydrogen abundance is $X \leq 0.01$.

Also indicated is the type of models that have been selected:

- **PreMS** - pre-main sequence models,
- **ZAMS** - near the beginning of the main sequence,
- **MS** - main sequence models,
- **TAMS** - near the end of the main sequence,
- **PostMS** - post-main sequence models.

In this exercise we have proposed the adoption of the reference solar values and physical constants as given at:
`http://www.astro.up.pt/corot/ntools/docs/CoRoT_ESTA_Files.pdf`

3 Comparison: global parameters

The global parameters for the models calculated by the different codes, following the specific-ations listed in Table 1, are given in Tables 2-3 for models in the main sequence (Cases 1.1, 1.2, 1.6 and 1.7) and in Table 4 for models off the main sequence (Cases 1.3, 1.4 and 1.5). The tables include the spread in the parameters (x_i) as defined by

$$\Delta_{\rm A} \equiv 2 \ \frac{\max(x_i) - \min(x_i)}{\max(x_i) + \min(x_i)} \ .$$

The letter A indicates which set of models has been used:

- A=all - all values listed have been used,
- A=4 - only values for codes [ASTEC, CESAM, CLES, STAROX] are used,
- A=3 - only values for codes [ASTEC, CESAM, CLES] are used.

The reference set of physics has not been fully implemented in all codes. Consequently part of the differences found in all Tables (2-4) are still mainly a consequence of the differences in the physics used for the calculations.

For the set of codes that have followed more closely the physics specified for the comparison, the differences are significantly smaller as illustrated by Δ_4 and Δ_3.

4 Comparison: evolutionary sequences

The evolutionary sequences, when available, for all targets are shown in Figs 2-5. The results are fairly consistent as expected from the comparison of the global parameters of the target models.

In this exercise we have already iterated, see Monteiro et al. (2005), Lebreton & Monteiro (2005) and Christensen-Dalsgaard (2005b), in order to reduce the relative differences. But in some cases further work will need to be done, and in particular the models will have to be calculated following the specifications as some of the differences are yet due to the use of a different set of physics.

5 Discussion

It is shown here that the models calculated by seven different codes are - to first order - consistent, as one would expect. The relative differences in the global parameters, listed in Tables 2-4, are small. The specifications for the targets have not been precisely followed and the reference set of physics defined for this exercise is also not yet fully implemented in some of the codes. Those are the two major reasons why there is a difference in the values of the global parameters ($R, L, T_{\rm eff}$) found here. This difference is strongly reduced when we compare the output of codes where the physics have been adapted to the required specifications.

For the global parameters the differences are the largest for the age. This was to be expected as different codes use different definitions of the point in the evolution for age zero. A useful outcome of this exercise should be to adopt a common definition that should be used by all codes to set the age of the models. Age, by being the quantity that measures the cumulative effect of all differences (physics and numeric) is the most sensitive global stellar parameter for indicating the consistency between codes. Further work on understanding what are the sources of the differences in the estimated age is required.

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Table 1: Description of the target models proposed under Task1 of the CoRoT/ESTA Model Comparison project. The standard symbols are used. The stellar mass (M) and the He core mass ($M_{\rm HeC}$) are in units of the solar mass ($M_{\odot}$), while the overshoot extent ($\ell_{\rm ov}$) is in pressure scale heights (H_p). An indication of the location of these targets in the HR diagram is given in Fig. 1.

Cases:	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**
Parameters:							
$M/M_{\odot}$	0.9	1.2	1.2	2.0	2.0	3.0	5.0
X_0	0.70	0.70	0.73	0.70	0.72	0.71	0.70
Y_0	0.28	0.28	0.26	0.28	0.26	0.28	0.28
Z_0	0.02	0.02	0.01	0.02	0.02	0.01	0.02
$\ell_{\rm ov}/H_p$	0.0	0.0	0.0	0.0	0.15	0.0	0.0
Target models:							
X_c	0.35	0.69	-	-	0.01	0.69	0.35
T_c	-	-	-	1.9×10^7	-	-	-
$M_{\rm HeC}/M_{\odot}$	-	-	0.1	-	-	-	-
Type:	MS	ZAMS	PostMS	PreMS	TAMS	ZAMS	MS

Table 2: Global parameters for the models in the main sequence calculated using different stellar evolutionary codes. The standard symbols are used. Age is in Myrs, while mass (M), radius (R) and luminosity (L) are in solar units ($M_\odot, R_\odot, L_\odot$). The temperatures and density are in CGS. The evolutionary sequences leading to these models are shown in Fig. 2.

	Age	$\frac{R}{R_\odot}$	$\frac{L}{L_\odot}$	$T_{\rm eff}$	$\frac{T_c}{10^7}$	ρ_c
Case 1.1:						
ASTEC	6 709	0.8925	0.6265	5 441	1.447	151.4
CESAM	6 782	0.8916	0.6262	5 443	1.448	150.9
CLES	6 895	0.8958	0.6246	5 427	1.447	150.9
FRANEC	6 839	0.8997	0.6273	5 413	1.446	151.0
GENEC	7 024	0.8871	0.5985	5 395	1.433	149.9
STAROX	6 675	0.8926	0.6259	5 439	1.446	151.8
TGEC	6 539	0.8942	0.6504	5 489	1.458	153.9
$\Delta_{\rm all}$	7.2%	1.4%	8.3%	1.7%	1.7%	2.7%
Δ_4	3.3%	0.5%	0.3%	0.3%	0.1%	0.6%
Case 1.2:						
ASTEC	074.6	1.150	1.793	6 234	1.581	87.23
CESAM	096.7	1.146	1.776	6 231	1.577	86.65
CLES	102.9	1.146	1.776	6 230	1.576	86.52
FRANEC	099.1	1.170	1.781	6 161	1.575	86.69
GENEC	079.0	1.144	1.760	6 220	1.573	86.34
STAROX	101.5	1.148	1.778	6 225	1.576	86.84
TGEC	106.0	1.148	1.849	6 290	1.589	88.31
$\Delta_{\rm all}$	34.8%	2.2%	4.9%	2.1%	1.0%	2.3%
Δ_4	31.9%	0.3%	0.9%	0.1%	0.3%	0.8%

Table 3: Global parameters for the models in the main sequence calculated using different stellar evolutionary codes. The standard symbols are used. Age is in Myrs, while mass (M), radius (R) and luminosity (L) are in solar units ($M_\odot, R_\odot, L_\odot$). The temperatures and density are in CGS. The evolutionary sequences leading to these models are shown in Fig. 3.

	Age	$\frac{R}{R_\odot}$	$\frac{L}{L_\odot}$	$T_{\rm eff}$	$\frac{T_c}{10^7}$	ρ_c
Case 1.6:						
ASTEC	13.32	1.859	101.5	13 451	2.483	42.94
CESAM	14.47	1.854	101.4	13 466	2.486	43.04
CLES	14.76	1.853	101.5	13 475	2.486	43.02
FRANEC	14.86	1.859	101.7	13 440	2.481	42.88
GENEC	14.77	1.8560	100.4	13 423	2.488	42.60
STAROX	14.46	1.855	101.6	13 468	2.4872	43.17
$\Delta_{\rm all}$	10.9%	0.3%	1.3%	0.4%	0.3%	1.3%
Δ_4	10.3%	0.3%	0.2%	0.2%	0.2%	0.5%
Case 1.7:						
ASTEC	56.37	3.889	746.1	15 312	2.832	19.60
CESAM	55.94	3.854	739.6	15 348	2.836	19.76
CLES	56.53	3.862	741.1	15 339	2.837	19.78
FRANEC	56.86	3.875	748.2	15 332	2.836	19.73
GENEC	52.74	3.734	703.2	15 395	2.865	19.52
STAROX	55.60	3.871	745.0	15 342	2.838	19.76
$\Delta_{\rm all}$	7.5%	4.1%	6.2%	0.5%	1.2%	1.3%
Δ_4	1.7%	0.9%	0.9%	0.2%	0.2%	0.9%

Table 4: Global parameters for the models off the main sequence calculated using different stellar evolutionary codes. The standard symbols are used. Age is in Myrs, while mass (M), mass of the helium core (M_{HeC}), radius (R) and luminosity (L) are in solar units ($M_\odot, R_\odot, L_\odot$). The temperatures and density are in CGS. The evolutionary sequences leading to these models are shown in Figs 4-5.

	Age	$\frac{R}{R_\odot}$	$\frac{L}{L_\odot}$	T_{eff}	$\frac{T_c}{10^7}$	ρ_c
Case 1.3:						
ASTEC	4 323	2.159	5.520	6 026	2.185	3 253
CLES	4 454	2.168	5.628	6 043	2.201	3 108
FRANEC	4 278	2.238	5.588	5 931	2.195	3 280
GENEC	4 511	2.149	5.353	5 994	2.194	3 288
Δ_{all}	5.3%	4.0%	5.0%	1.9%	0.8%	5.6%
Δ_4	3.0%	0.4%	1.9%	0.3%	0.8%	4.6%
Case 1.4:						
CESAM	7.043	1.866	15.80	8 431	1.900	49.22
CLES	7.579	1.871	16.09	8 461	1.900	49.89
FRANEC	7.814	1.876	16.24	8 457	1.897	50.03
GENEC	7.685	1.853	15.24	8 386	1.900	48.90
STAROX	8.292	1.862	15.64	8 419	1.900	49.20
TGEC	7.200	1.839	15.27	8 427	1.891	46.86
Δ_{all}	16.3%	2.0%	6.4%	0.9%	0.5%	6.5%
Δ_4	16.3%	0.4%	2.9%	0.5%	0.0%	1.4%
Case 1.5:						
ASTEC	1 175	3.539	22.67	6 701	2.787	130.9
CESAM	1 184	3.543	22.91	6 716	2.794	131.8
CLES	1 202	3.549	23.09	6 723	2.797	131.7
GENEC	1 189	3.478	22.35	6 735	2.794	131.7
STAROX	1 208	3.663	23.37	6 637	2.802	131.8
Δ_{all}	2.7%	5.2%	4.5%	1.5%	0.6%	0.7%
Δ_3	2.7%	3.4%	3.0%	1.3%	0.6%	0.7%

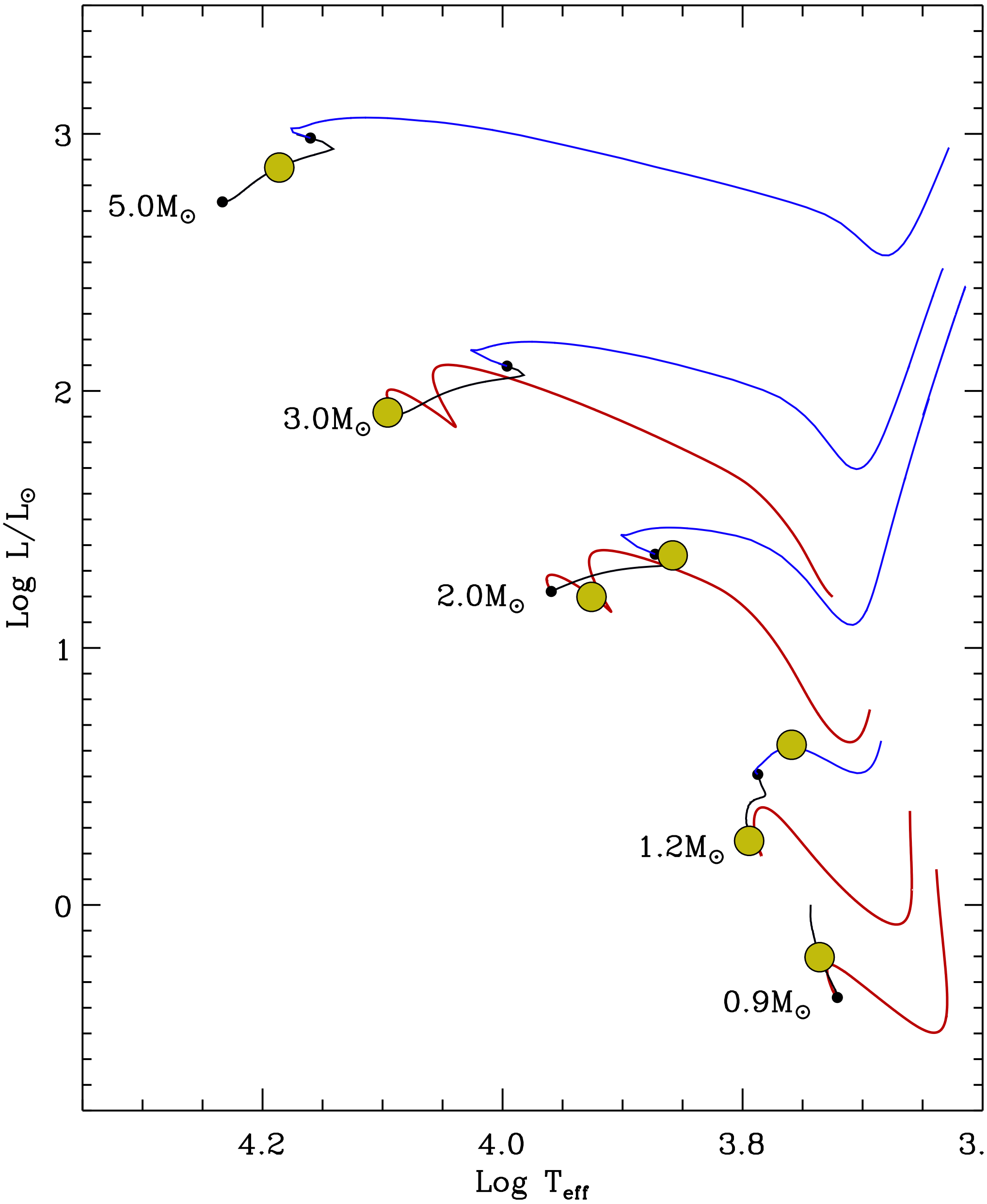

Figure 1: Plot of the distribution of the targets in the HR diagram (see Tables 1). Red lines correspond to the pre-main sequence, black lines to the main sequence and blue lines to the post-main sequence evolution for the masses indicated. The targets are ordered in mass and age along the HR diagram, corresponding to Case 1.1 (bottom-right) up to Case 1.7 (top-left).

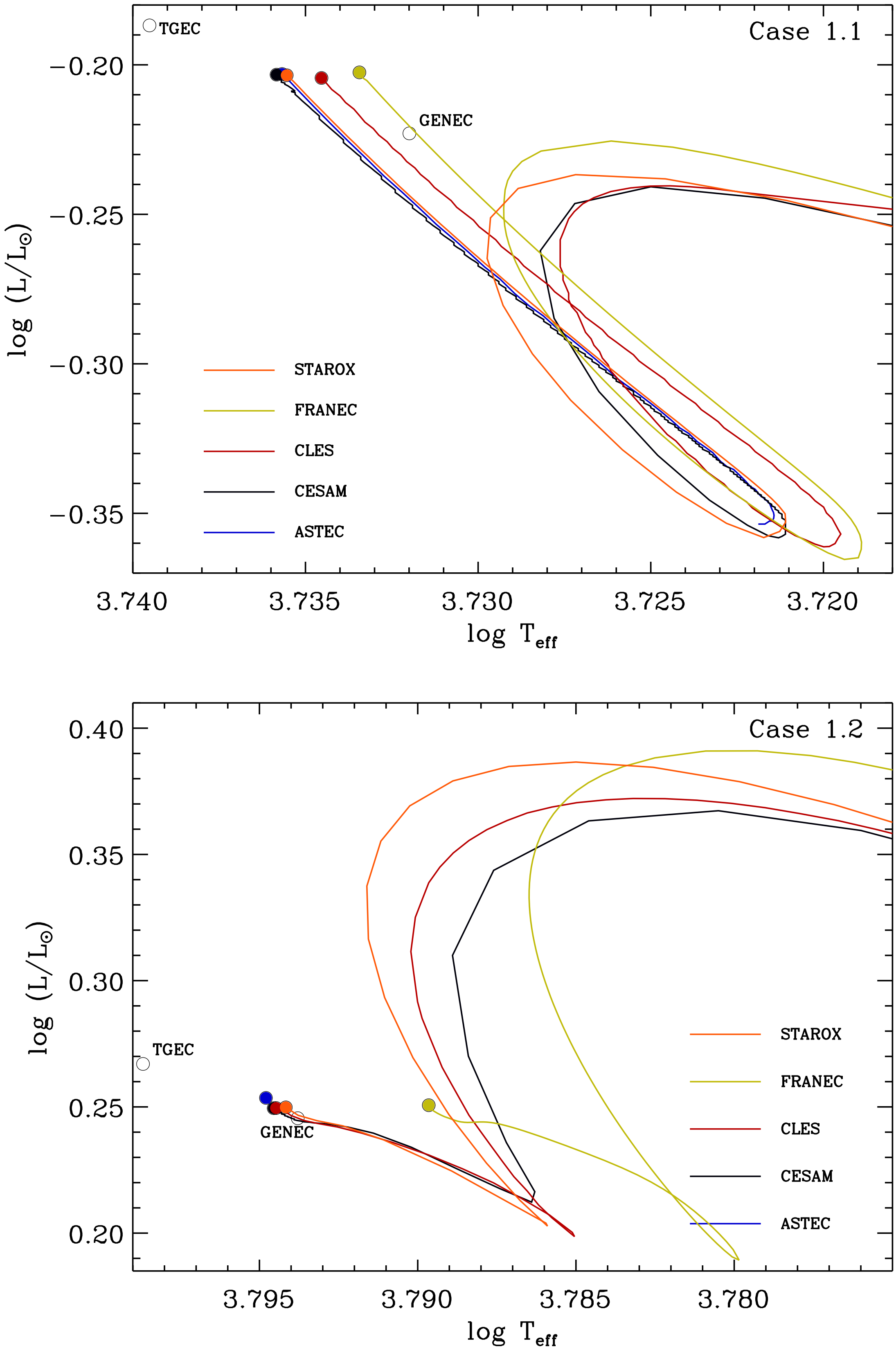

Figure 2: Plot of the evolutionary sequences and final target model (see Tables 2) for Cases 1.1 and 1.2. These are both main-sequence models of low mass stars (solar-type).

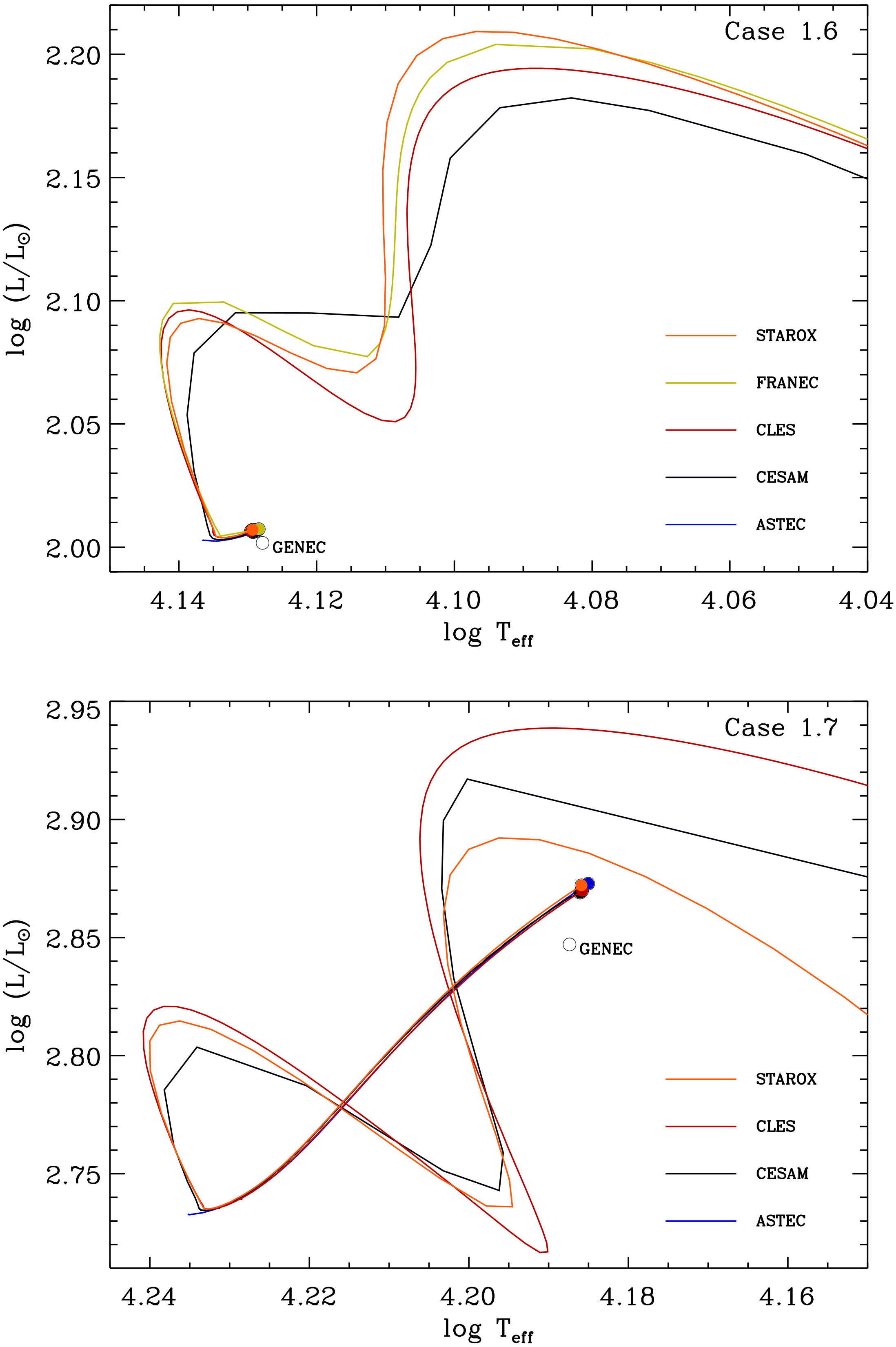

Figure 3: Plot of the evolutionary sequences and final target model (see Tables 3) for Cases 1.6 and 1.7. These correspond to main sequence models of high mass stars.

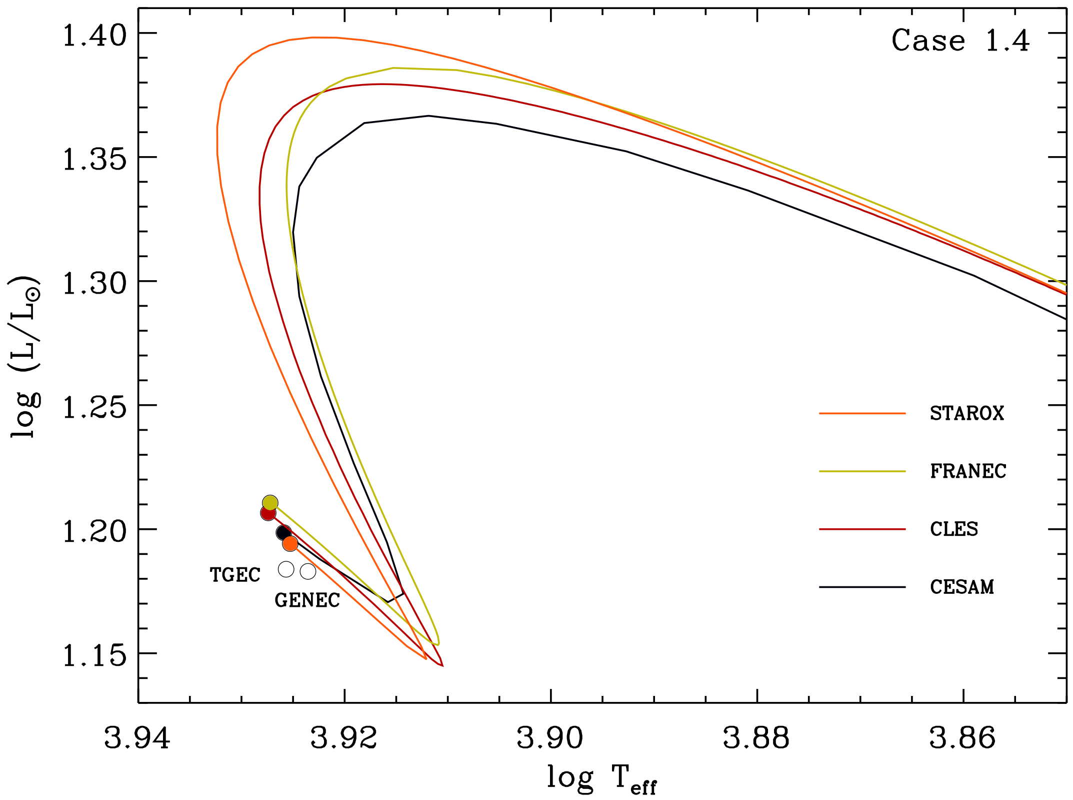

Figure 4: Plot of the evolutionary sequences and final target model (see Tables 4) for Case 1.4. This is a pre-main sequence model.

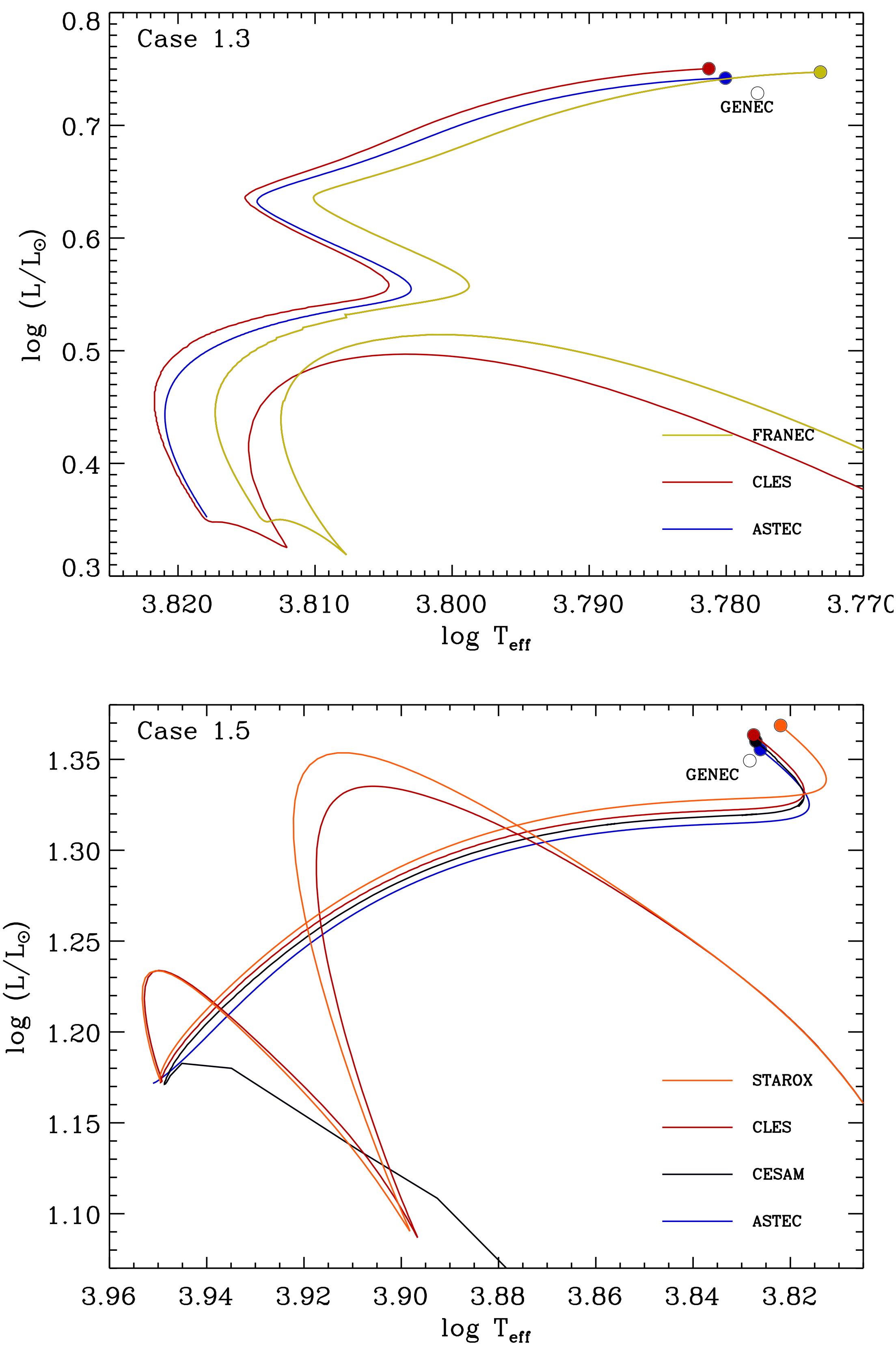

Figure 5: Plot of the evolutionary sequences and final target model (see Tables 4) for Cases 1.3 and 1.5. Case 1.3 is a highly evolved model while Case 1.5 is a model with overshoot.