Seismology Working Group

Evolution and Seismic Tools Activity

Report on Task 1 - Model Comparison

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and the ESTA Team

Roadmap

ESTA has aimed at contributing towards the preparation and exploration of the scientific results of CoRoT by extensively **test, compare and optimize numerical tools** used to calculate stellar models.

For model comparison the previous reports/events leading to this presentation are:

- *CoRoT Week 3, 2002*
  - 1 oral presentation
- *Meeting 1 (CoRoT Week 7)* , 2004
  - 1 oral presentation (+ 1 discussion)
- *Meeting 2 (CoRoT Week 8)*, 2005
  - 1 poster + 1 discussion + 1 report
- *Meeting 3 (Workshop Nice), 2005*
  - 15 oral presentations + 3 discussions (+ 1 report)
- *Meeting 4 (Workshop Aarhus)*, 2005
  - 17 oral presentations + 2 discussions (+ 2 reports)

Several codes have participated in this exercise. In order to reach the present agreement several iterations have been necessary. All code builders have used this work to correct, develop and optimize the evolution codes being compared.

Definition of Task 1

Under this task a few **specific, fully identified, stellar cases** have been proposed to compare the evolution codes. The physical assumptions proposed as the reference for the comparison have been defined and stellar models at different stages of evolution have been identified in order to cover as much as possible a representative range of stellar mass and age.

The comparison has addressed **how the physics and the numerical implementation of the physics may affect the result of different codes**. Discrepancies are to be used to optimize and develop the codes in order to produce consistent outputs between codes.

Both the global stellar parameters of the selected models and their interior structure have been compared. The evolutionary sequences leading to each model and the seismic properties are also compared in Task 1.

The key results are clues on what are the sources of the discrepancies and/or problems and what items required further development in the modelling.

Participating evolution codes

ASTEC:
Michael Bazot
Jørgen Christensen-Dalsgaard
Teresa C. Teixeira

CESAM:
Gabrielle Berthomieu
João M. Fernandes
Rafael Garrido
Marie Jo Goupil
Yveline Lebreton
João Pedro Marques
Pierre Morel
Andy Moya
Phi Nghiem
Pascal Lambert
Bernard Pichon
Janine Provost
Juan Carlos Suárez
Marian D. Suran

ATON:
Maria Pia di Mauro
Paolo Ventura

CLES :
Andrea Miglio
Josefina Montalbán
Arlette Noels
Richard Scuflaire
Anne Thoul

FRANEC:
Scilla Degl'Innocenti
Marcella Marconi
Pier Giorgio Prada Moroni

GARSTEC:
Achim Weiss

GENEC:
Patrick Eggenberger

TGEC:
Michael Bazot
Matthieu Castro
Sylvie Vauclair

STAROX:
Ian W. Roxburgh

Participation is open to all colleagues from *CoRoT contributing countries* willing to participate in the comparison and having access to an evolution code.

Up-to-date lists of participants and tools are maintained at the ESTA webpage. There is also a distribution list for emails used to exchange news on ESTA related activities.

Targets

These targets correspond to seven specific **fully identified stellar cases**, covering a representative range in stellar masses, ages and composition.

Case	$M/M_\odot$	Y_0	Z_0	α_{OV}	X_C	T_C	$M_{He,Cor}$	State
1.1	0.9	0.28	0.02	-	0.35	-	-	MS
1.2	1.2	0.28	0.02	-	0.69	-	-	ZAMS
1.3	1.2	0.26	0.01	-	-	-	$0.1M_\odot$	PostMS
1.4	2.0	0.28	0.02	-	-	$1.9\ 10^7$	-	PreMS
1.5	2.0	0.26	0.02	0.15	0.01	-	-	TAMS
1.6	3.0	0.28	0.01	-	0.69	-	-	ZAMS
1.7	5.0	0.28	0.02	-	0.35	-	-	MS

$M_{He,Cor}$ ⇨ mass of the central region where X<0.01

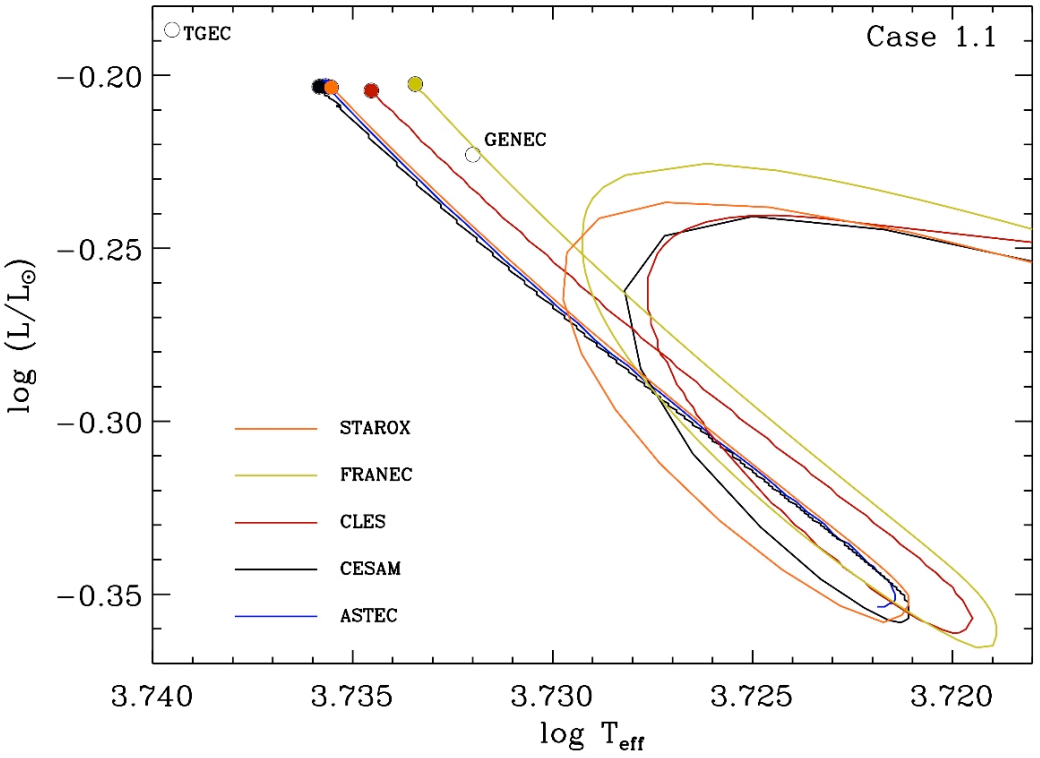
Reference physics

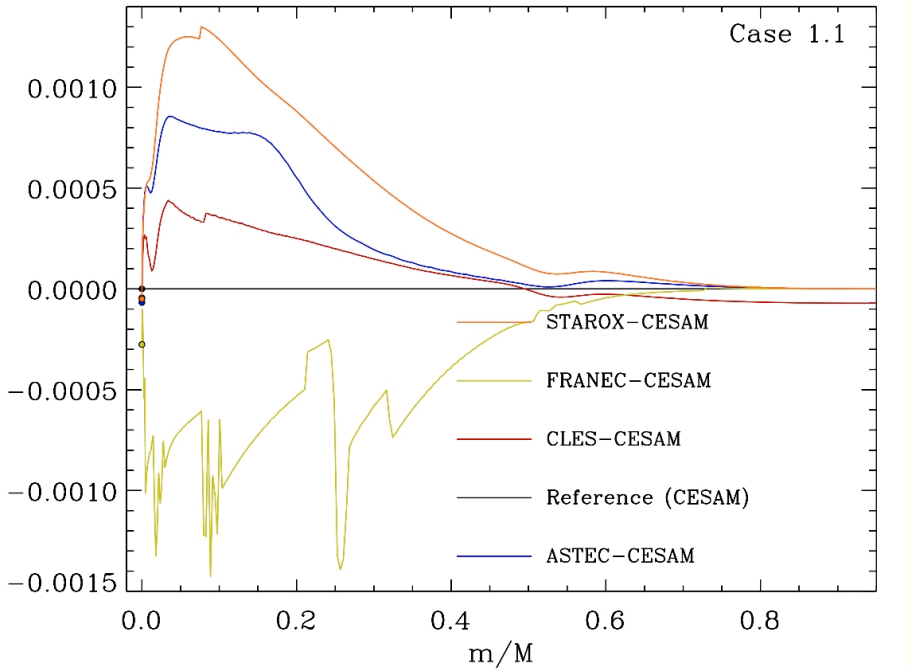
ITEM	Selection	References
EoS	OPAL	Rogers et al. (1996, 2001 Tables)
Opacities	OPAL + AF	Iglesias & Rogers (1996) Alexander & Fergusson (1994)
Reaction rates	NACRE	Angulo et al. (1999)
Convection	MLT (α = 1.6)	Bohm-Vitense (1958) + Henyey et al. (1965)
Overshoot	*none or* α_{ov}=0.15	Fully mixed + adiabatic stratification
Diffusion/settling	*none*	-
Mixture	Solar	Grevesse & Noels (1993)
Atmosphere	Grey	Eddington's

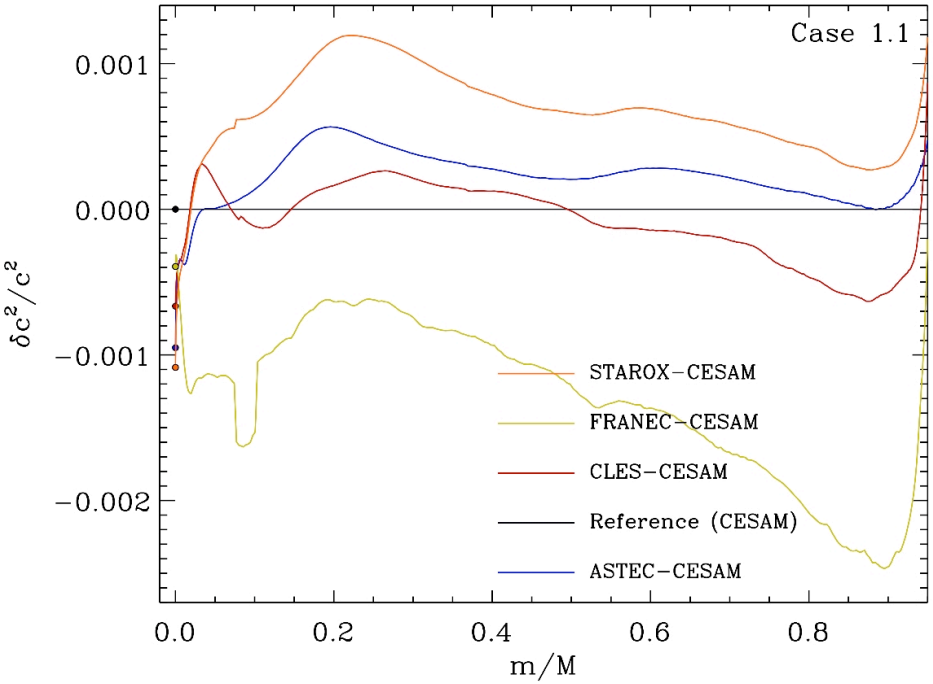
More detailed specifications of the physics have been provided in:

`http://www.astro.up.pt/corot/compmod/docs/Task1_Roadmap.pdf`

Case 1.1





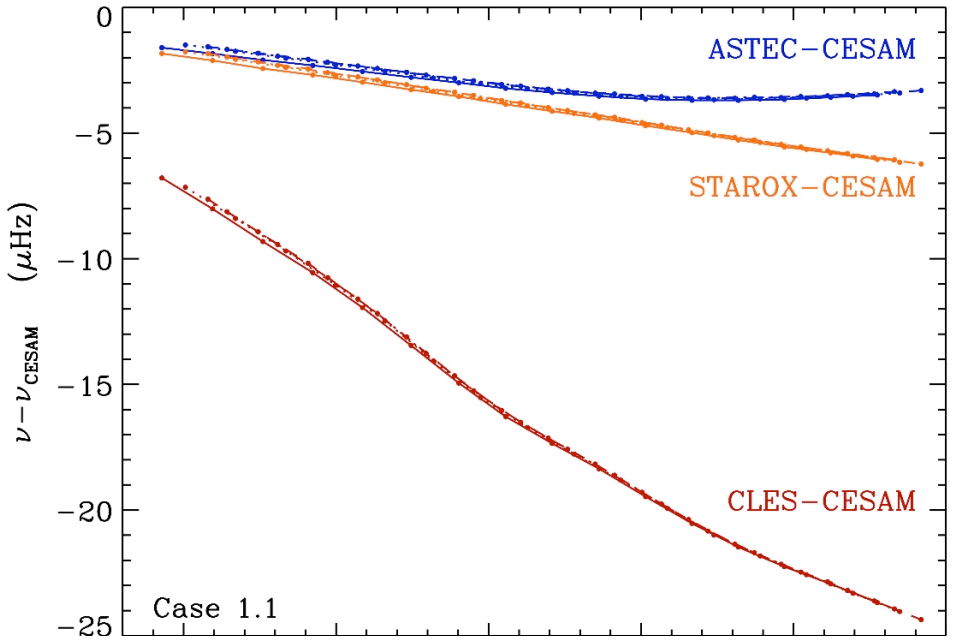


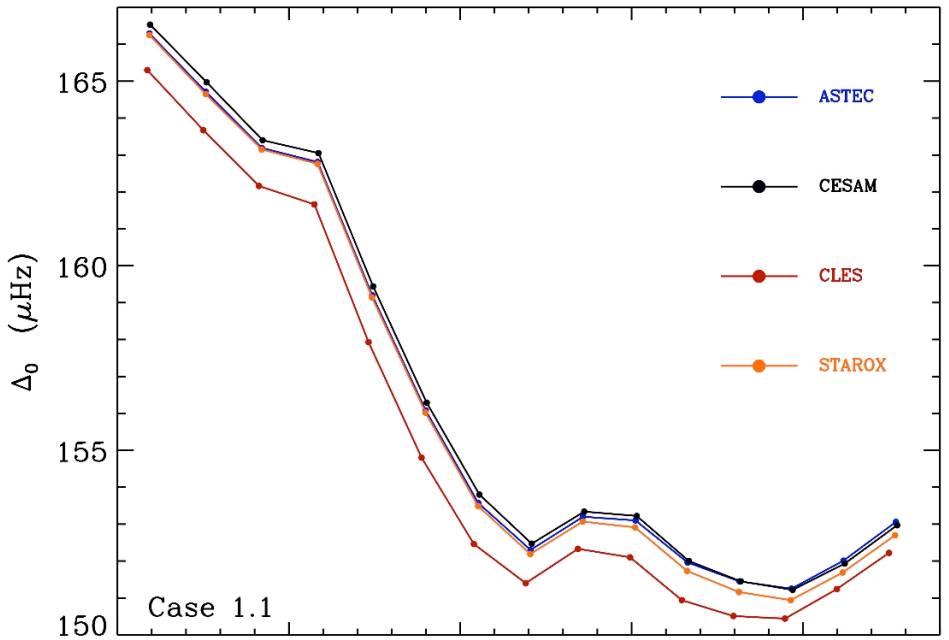
Main sequence (ZAMS) model:

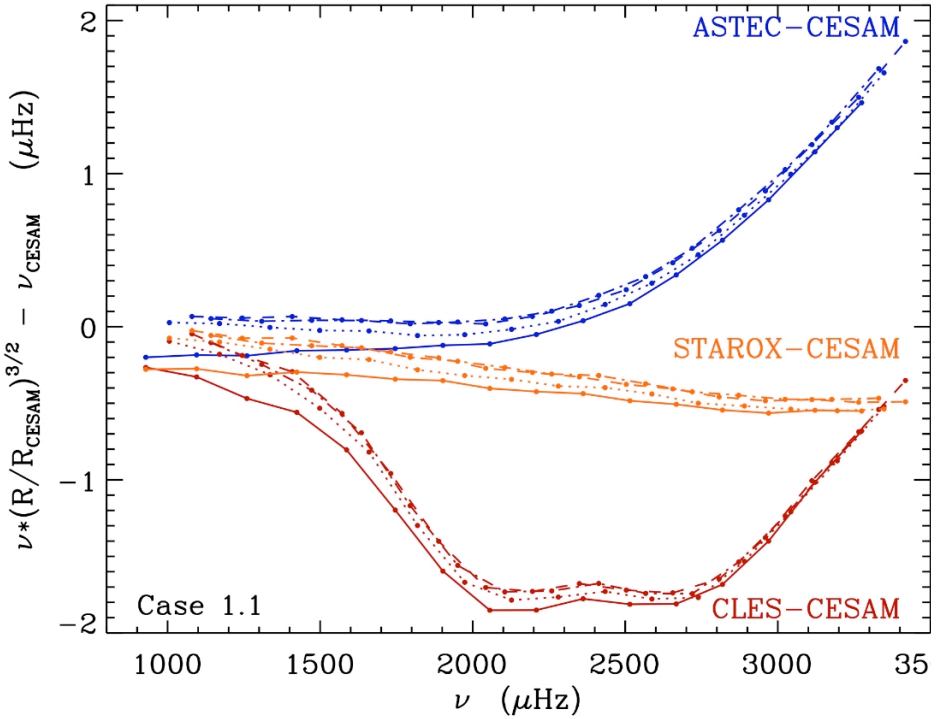
M = 0.9 $M_\odot$

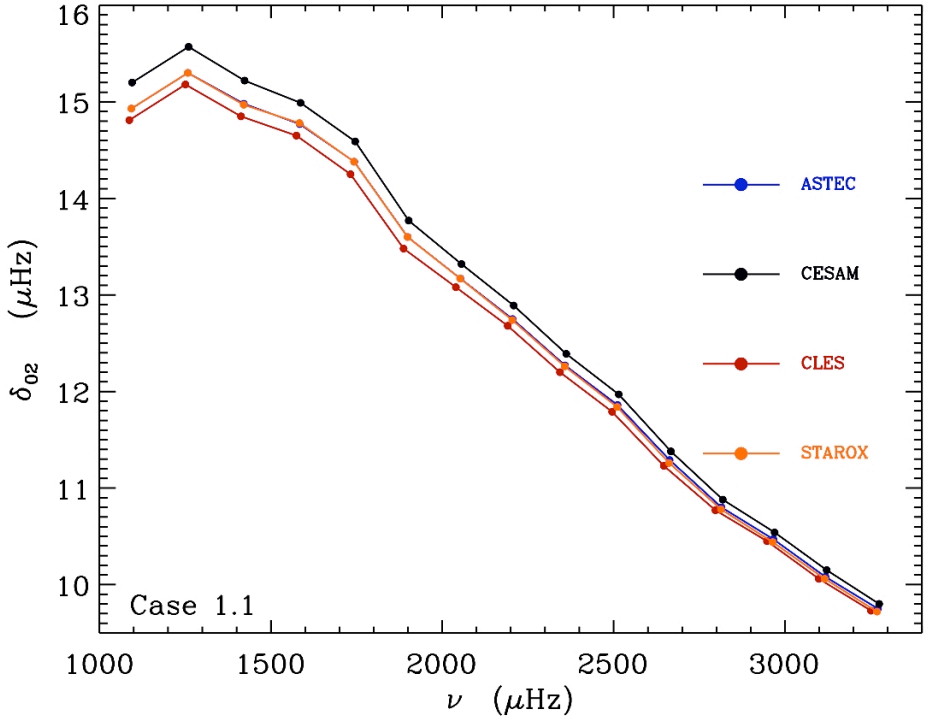
Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
ASTEC	6,709.1	0.8925	0.6265	5,441.0	1.4466	151.42
CESAM	6,782.0	0.8916	0.6262	5,443.0	1.4480	150.91
CLES	6,895.2	0.8958	0.6246	5,426.7	1.4470	150.90
FRANEC	6,839.0	0.8997	0.6273	5,413.0	1.4460	151.00
GENEC	7,024.0	0.8871	0.5985	5,395.0	1.4330	149.90
STAROX	6,674.5	0.8926	0.6259	5,439.3	1.4463	151.79
TGEC	6,539.0	0.8942	0.6504	5,489.3	1.4577	153.94
Spread (%)	7.2%	1.4%	8.3%	1.7%	1.7%	2.7%
	3.3%	0.5%	0.3%	0.3%	0.1%	0.6%

Case 1.1 - Seismic properties

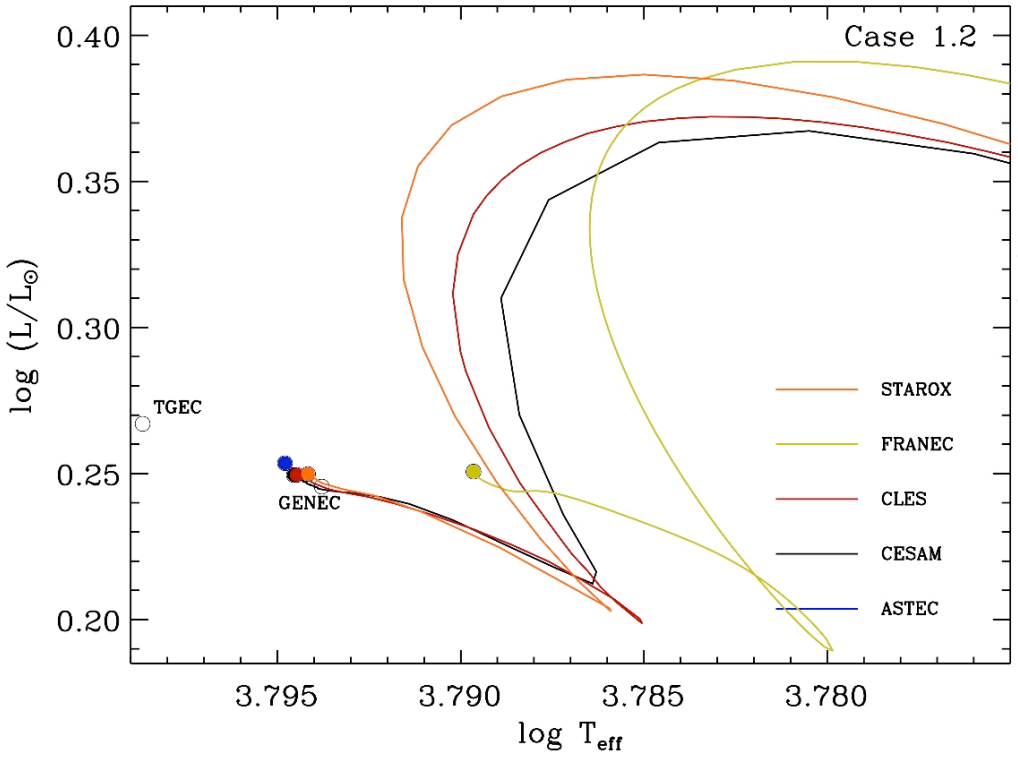


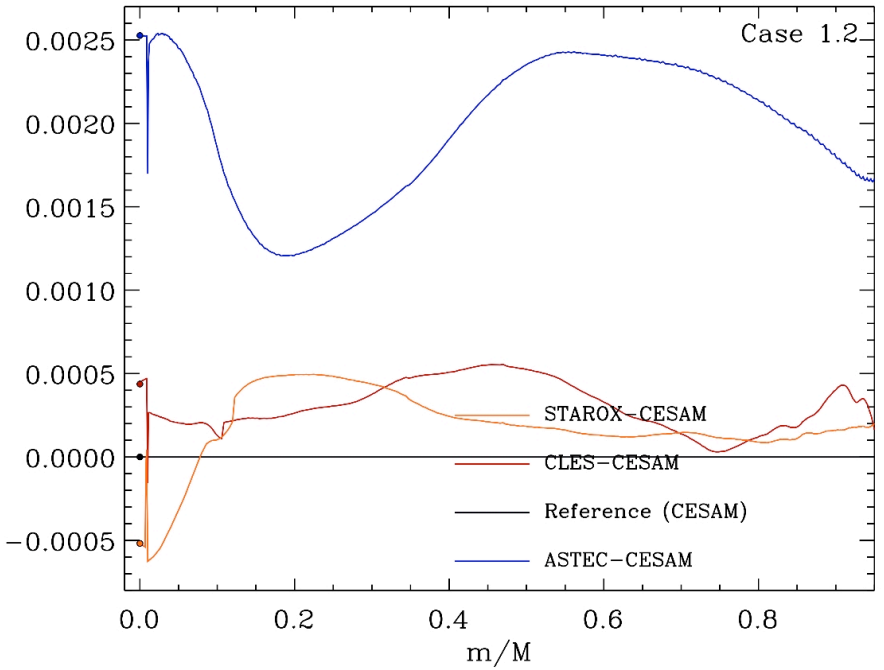


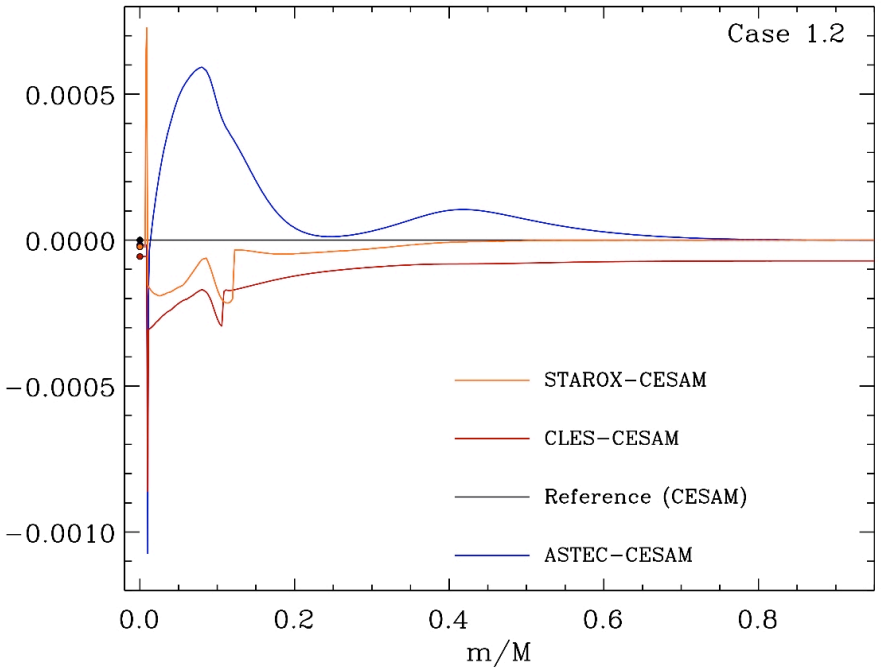




Case 1.2





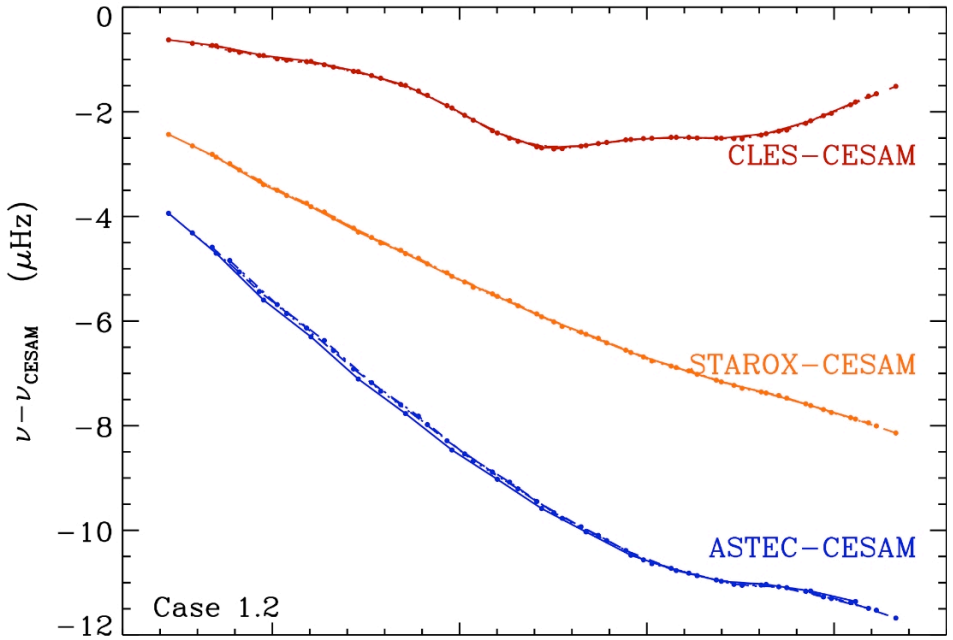


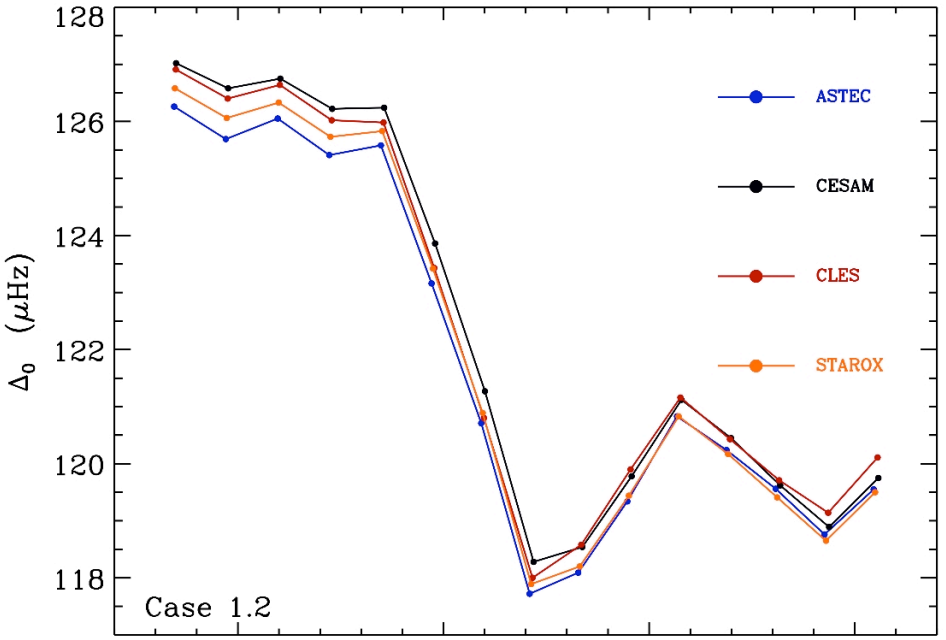
Main sequence model:

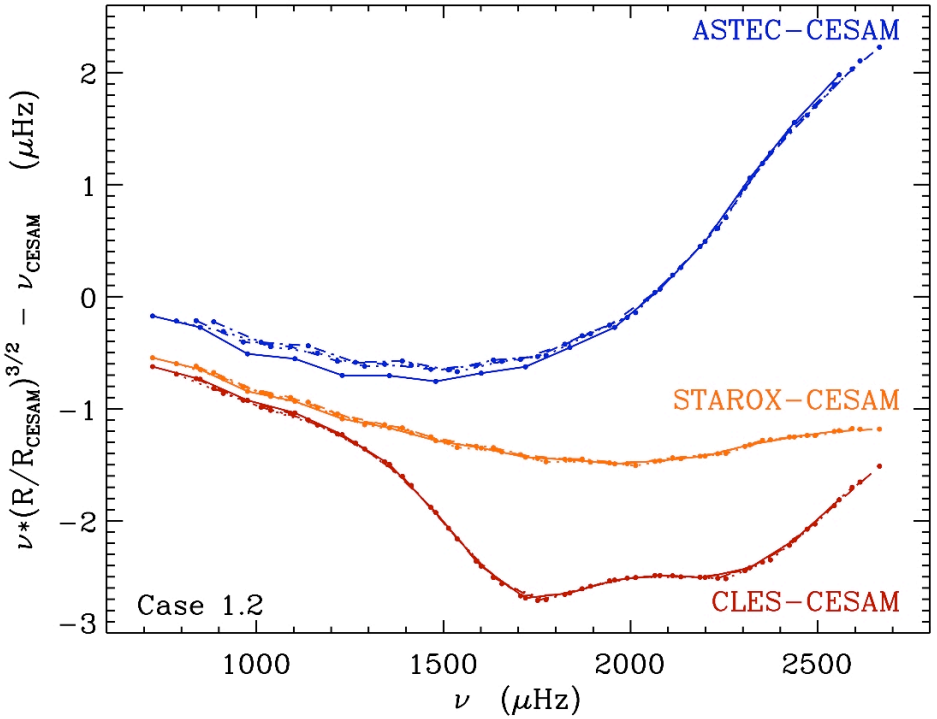
M = 1.2 $M_\odot$

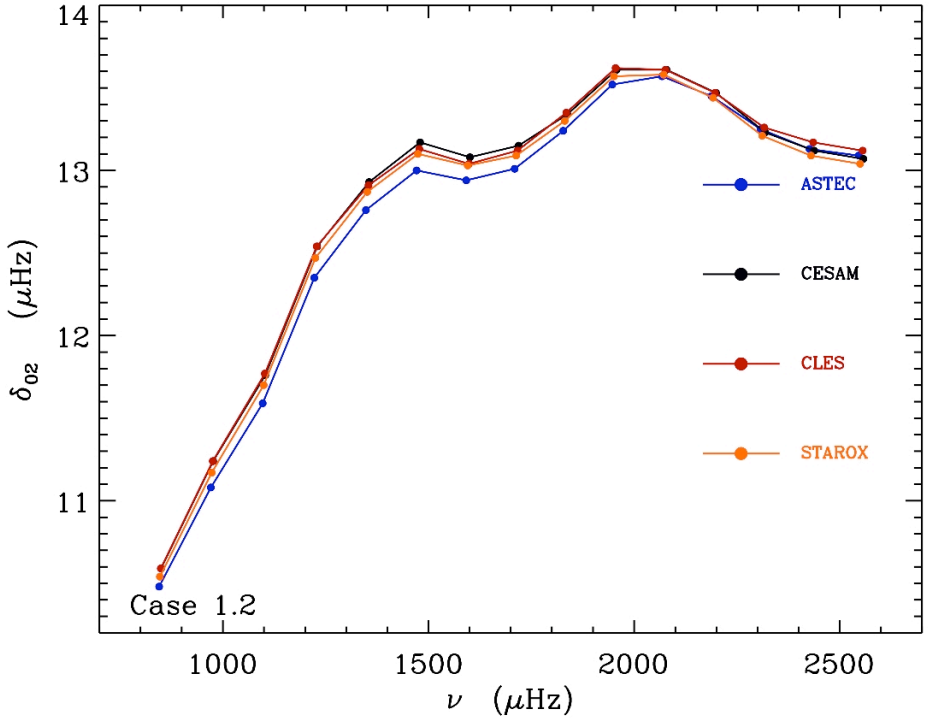
Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
ASTEC	74.59	1.1499	1.7929	6 234.4	1.5805	87.233
CESAM0	96.71	1.1459	1.7762	6 230.9	1.5766	86.647
CLES	102.92	1.1463	1.7764	6 229.8	1.5759	86.524
FRANEC	99.10	1.1700	1.7810	6 161.0	1.5750	86.690
GENEC	79.00	1.1440	1.7600	6 220.0	1.5730	86.340
STAROX	101.45	1.1483	1.7775	6 225.4	1.5758	86.841
TGEC	106.00	1.1483	1.8493	6 290.4	1.5894	88.306
Spread (%)	34.8%	2.2%	4.9%	2.1%	1.0%	2.3%
	31.9%	0.3%	0.9%	0.1%	0.3%	0.8%

Case 1.2 - Seismic properties

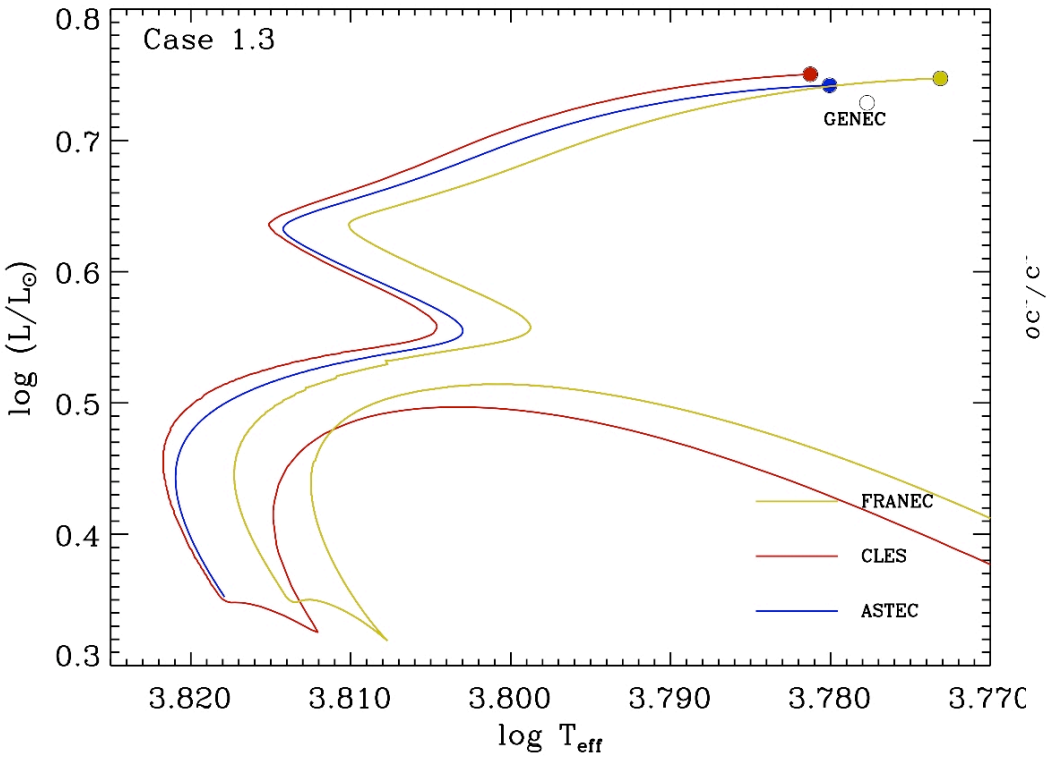


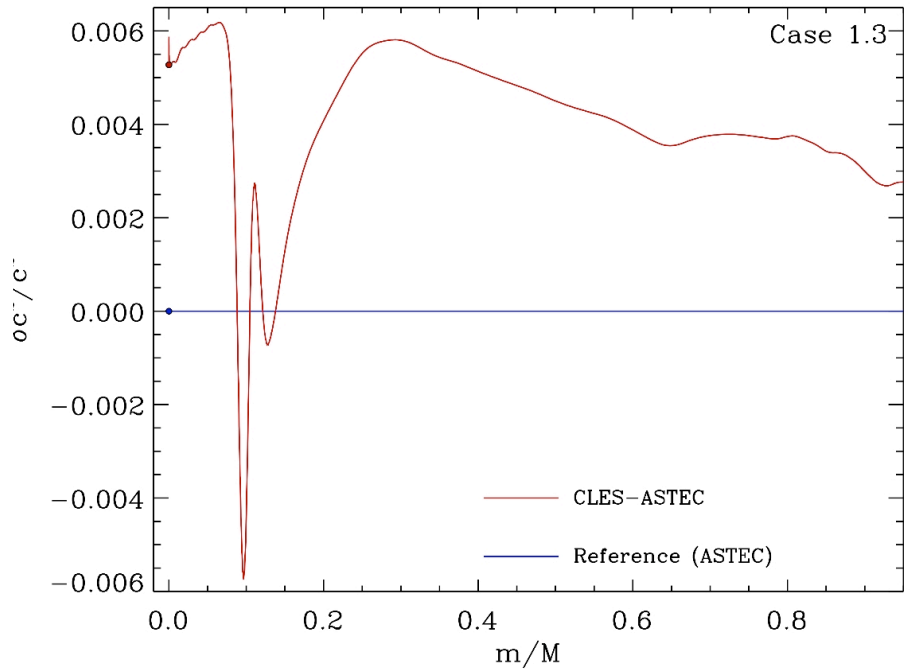


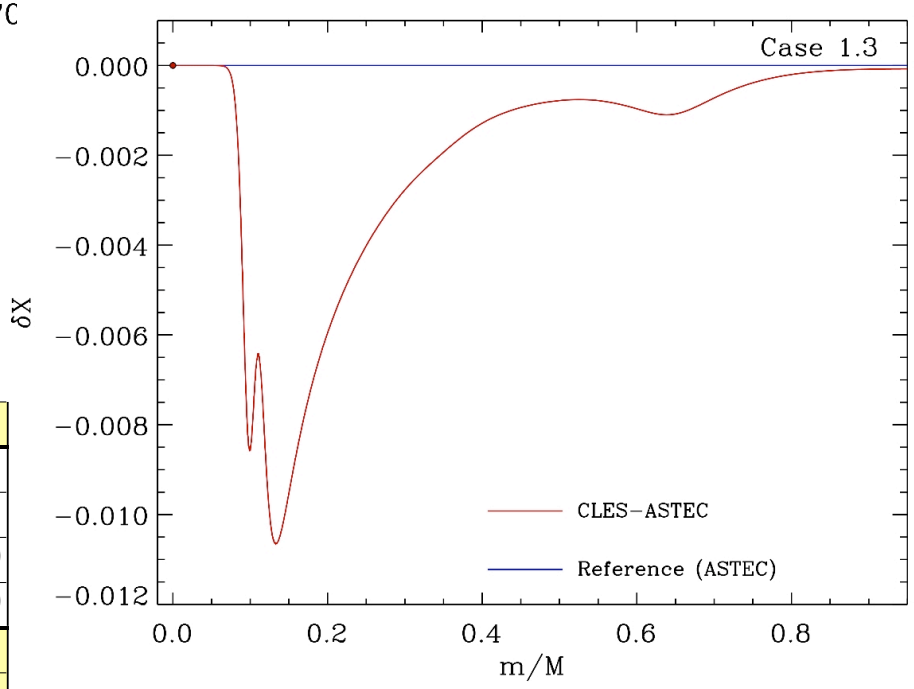




Case 1.3





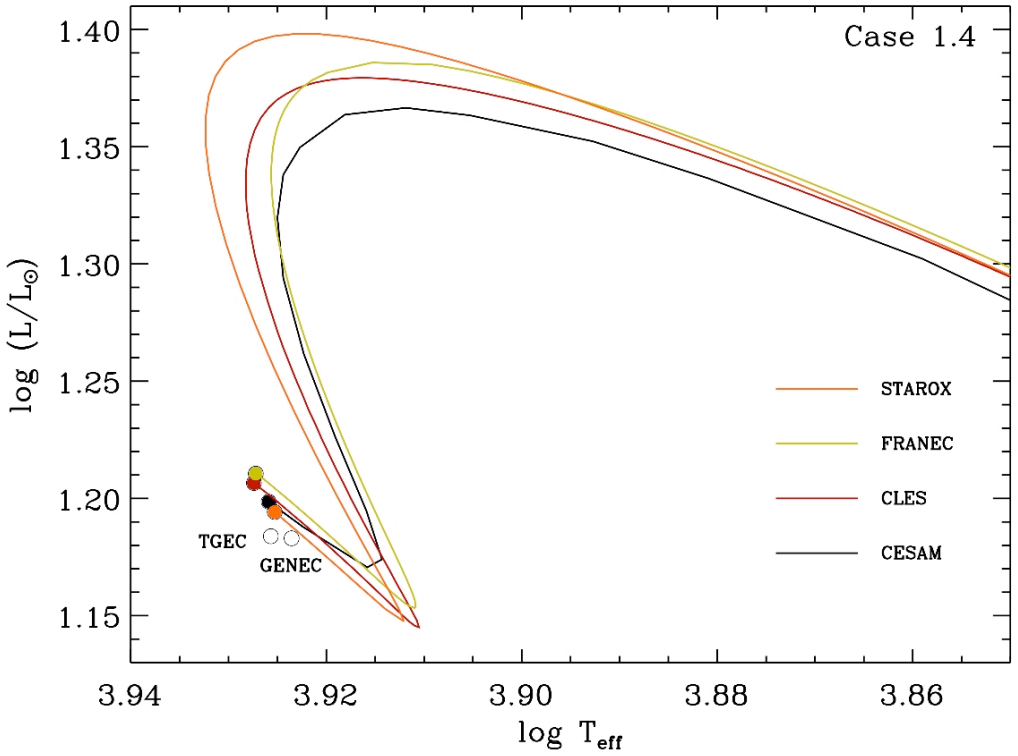


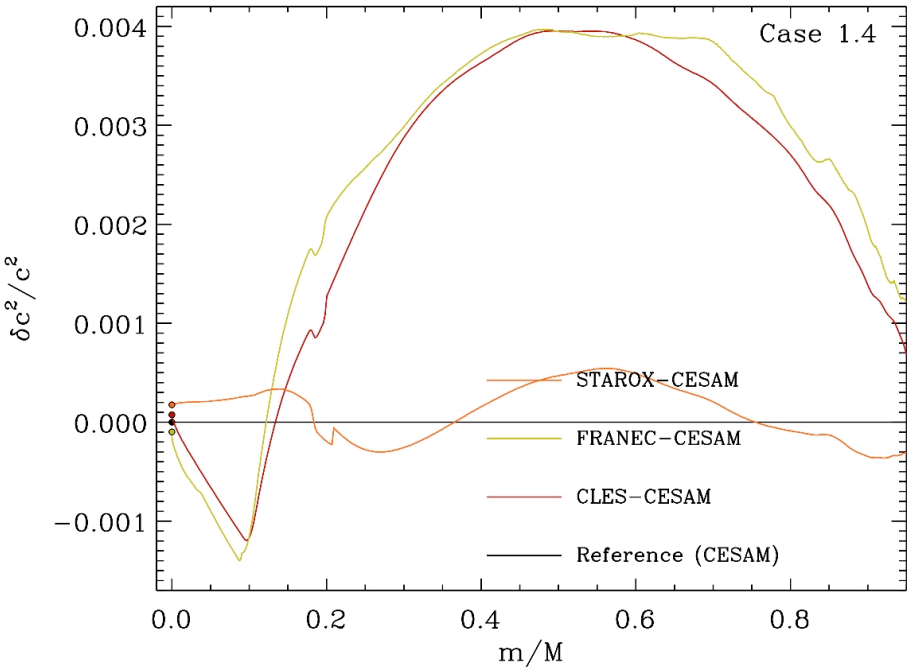
Post-main sequence (sub-giant) model:

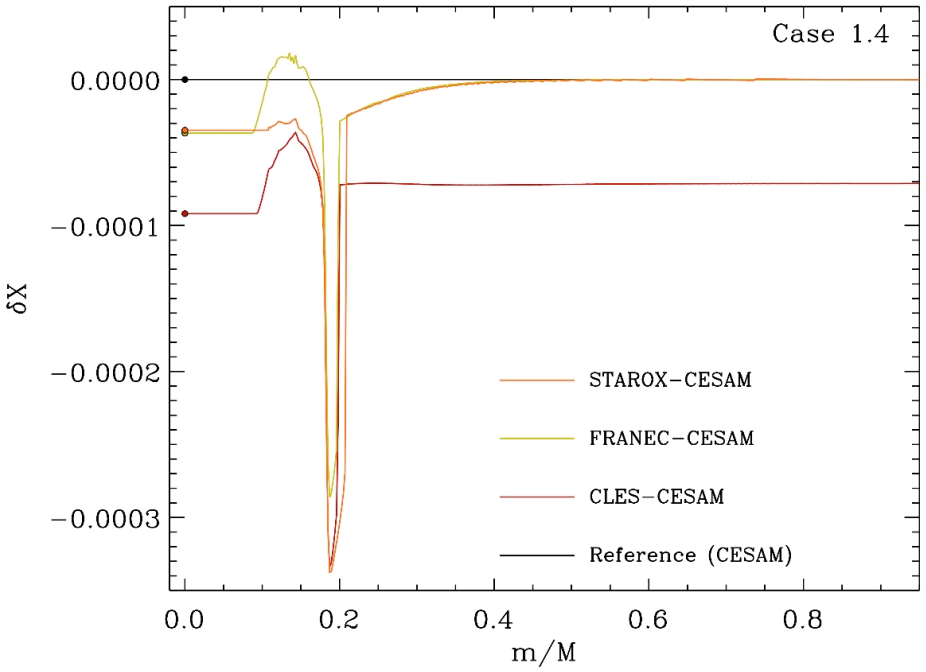
M = 1.2 $M_\odot$

Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
ASTEC	4 322.8	2.1594	5.5200	6 026.4	2.1845	3253.27
CLES	4 454.0	2.1683	5.6278	6 043.2	2.2013	3107.53
FRANEC	4 278.0	2.2376	5.5880	5 931.0	2.1950	3280.00
GENEC	4 511.0	2.1490	5.3530	5 994.0	2.1940	3288.00
Spread (%)	5.3%	4.0%	5.0%	1.9%	0.8%	5.6%
	3.0%	0.4%	1.9%	0.3%	0.8%	4.6%

Case 1.4





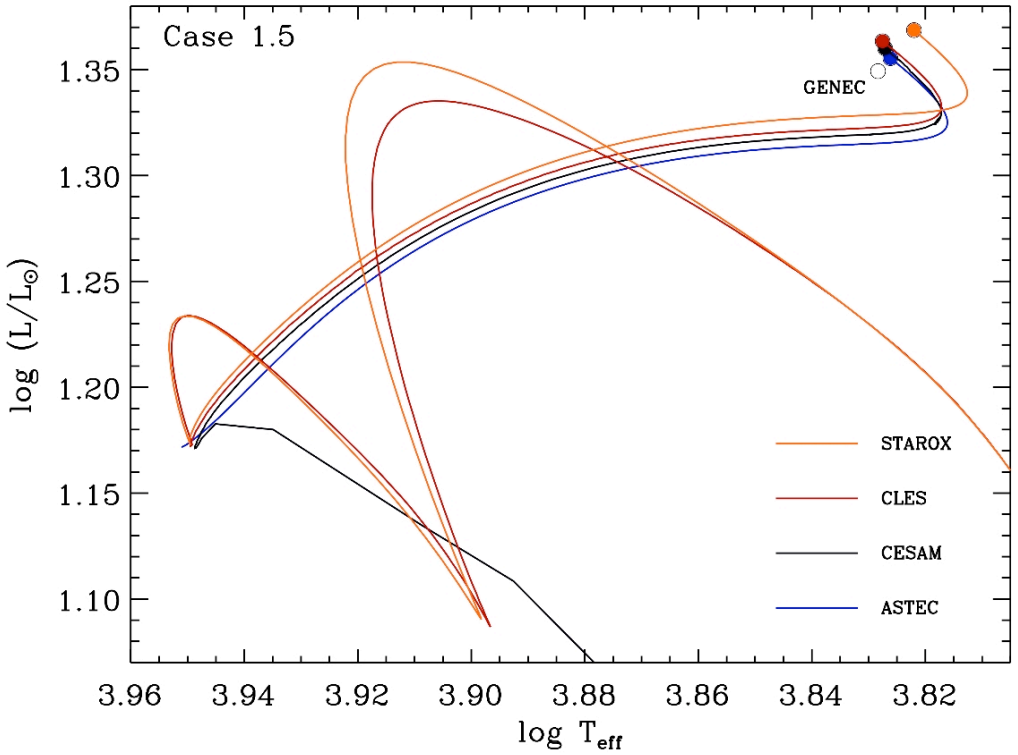


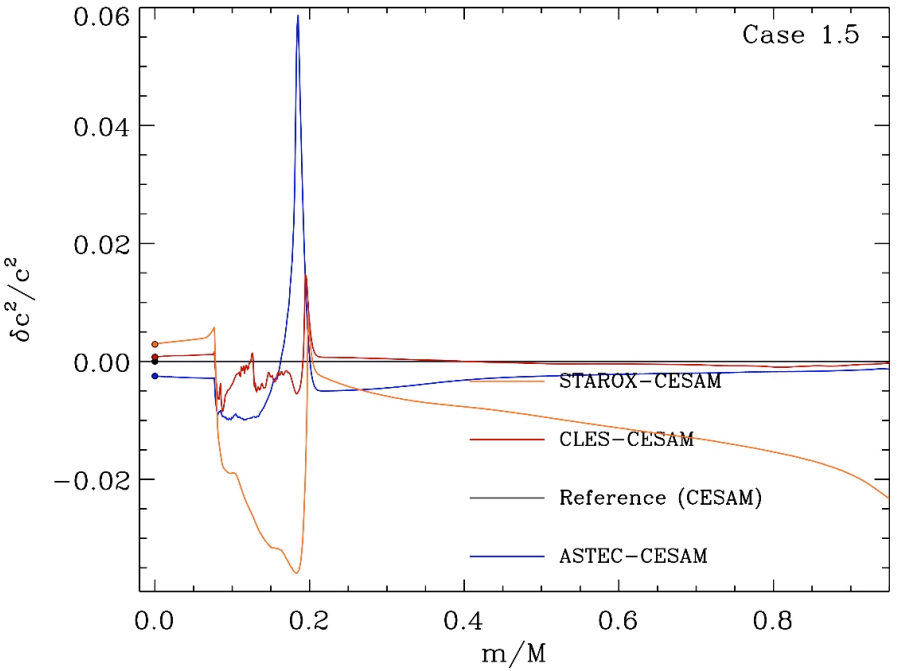
Pre-main sequence model:

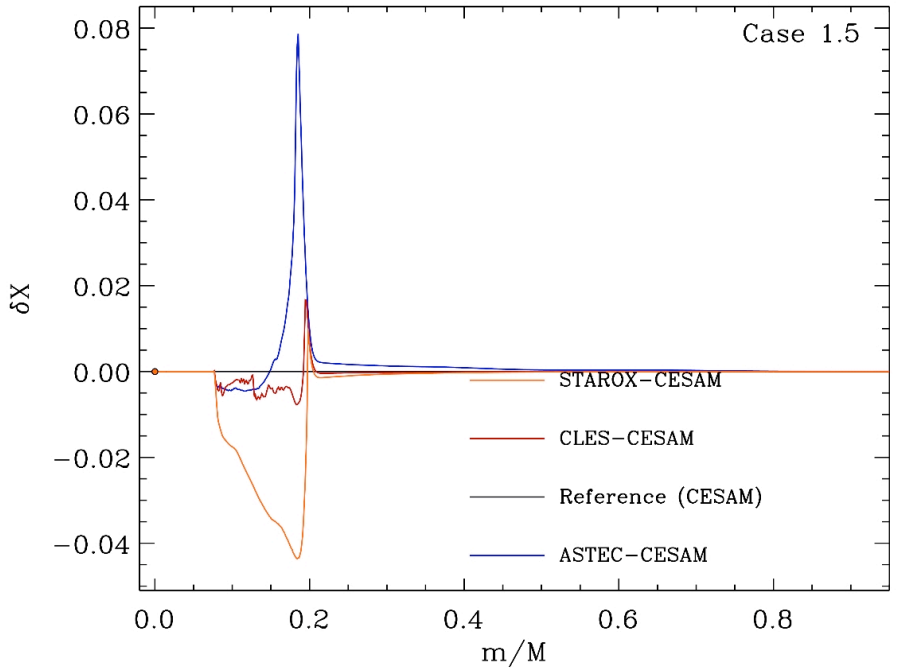
M = 2.0 $M_\odot$

Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
CESAM0	7.043	1.8663	15.798	8 431.3	1.8996	49.224
CLES	7.579	1.8705	16.091	8 460.7	1.9000	49.890
FRANEC	7.814	1.8760	16.240	8 457.0	1.8970	50.030
GENEC	7.685	1.8530	15.240	8 386.0	1.9000	48.900
STAROX	8.292	1.8623	15.639	8 419.3	1.9000	49.199
TGEC	7.200	1.8387	15.271	8 427.0	1.8914	46.864
Spread (%)	16.3%	2.0%	6.4%	0.9%	0.5%	6.5%
	16.3%	0.4%	2.9%	0.5%	0.0%	1.4%

Case 1.5





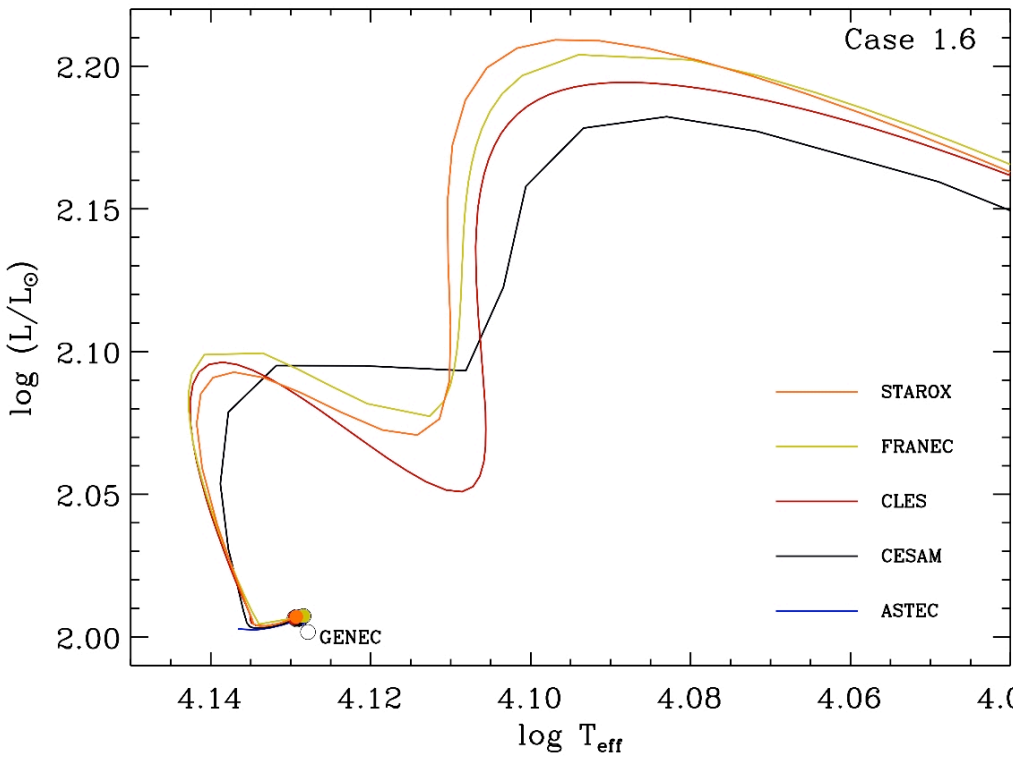


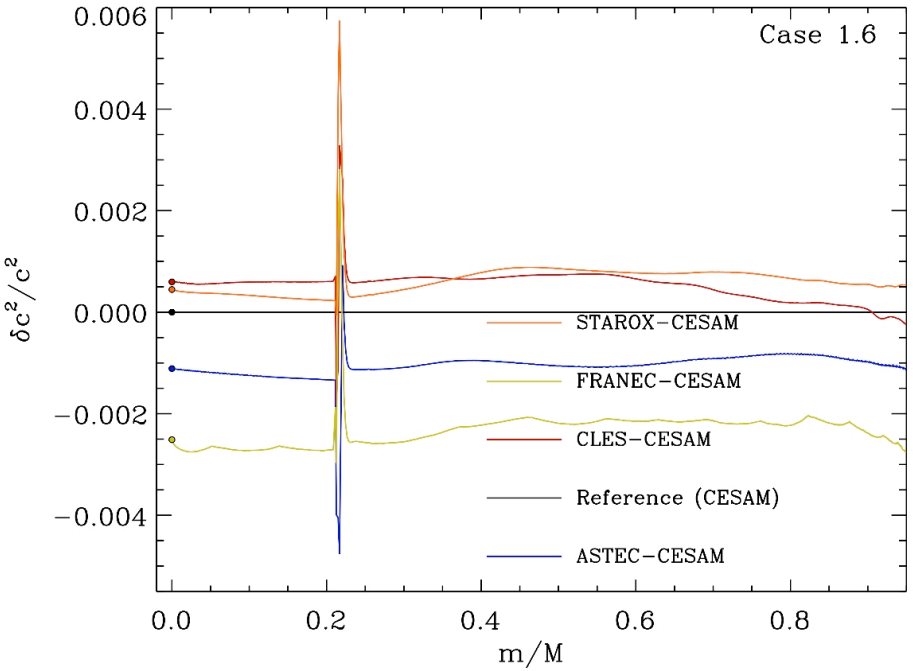
Post-main sequence (TAMS) model:

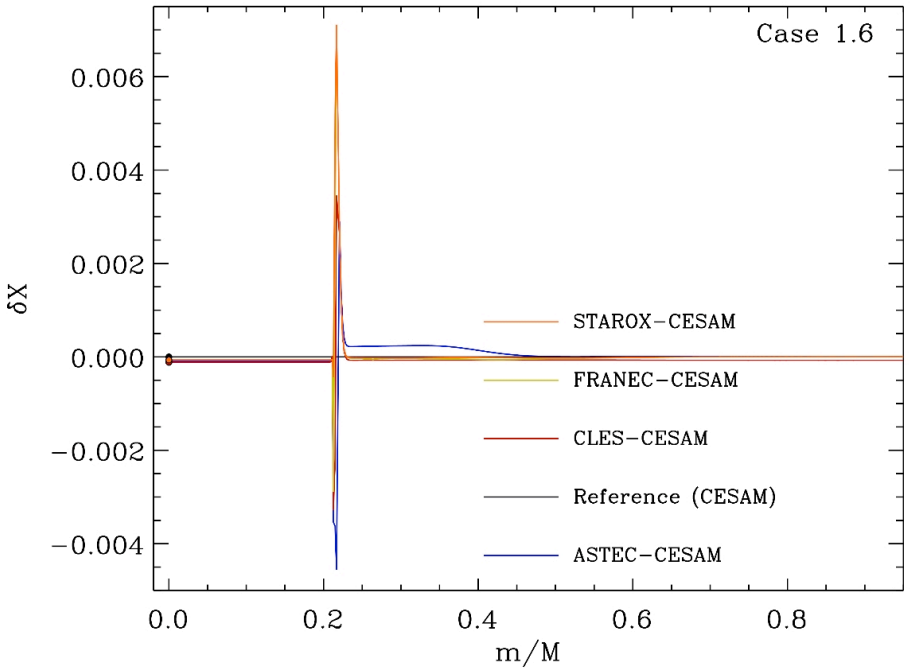
M = 2.0 $M_\odot$

Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
ASTEC	1 175.4	3.5390	22.668	6 701.2	2.7869	130.900
CESAM0	1 184.1	3.5427	22.909	6 715.5	2.7937	131.757
CLES	1 202.4	3.5491	23.090	6 722.6	2.7971	131.684
GENEC	1 189.0	3.4780	22.350	6 735.0	2.7940	131.700
STAROX	1 207.7	3.6627	23.369	6 637.4	2.8024	131.832
Spread (%)	2.7%	5.2%	4.5%	1.5%	0.6%	0.7%
	2.7%	3.4%	3.0%	1.3%	0.6%	0.7%

Case 1.6





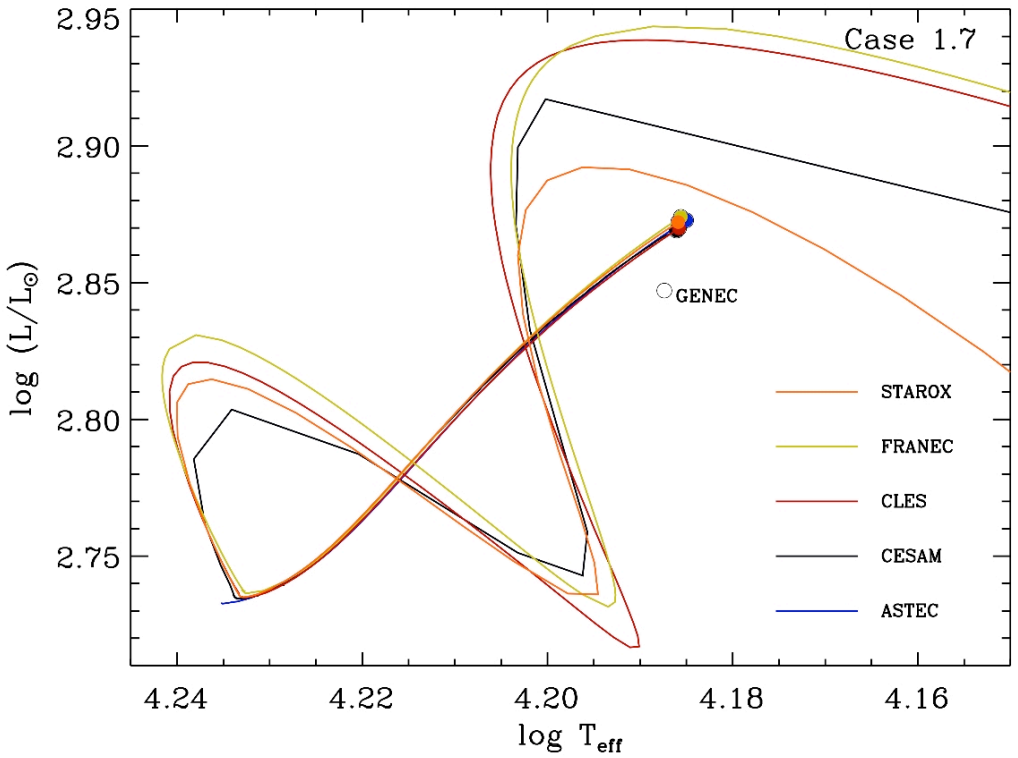


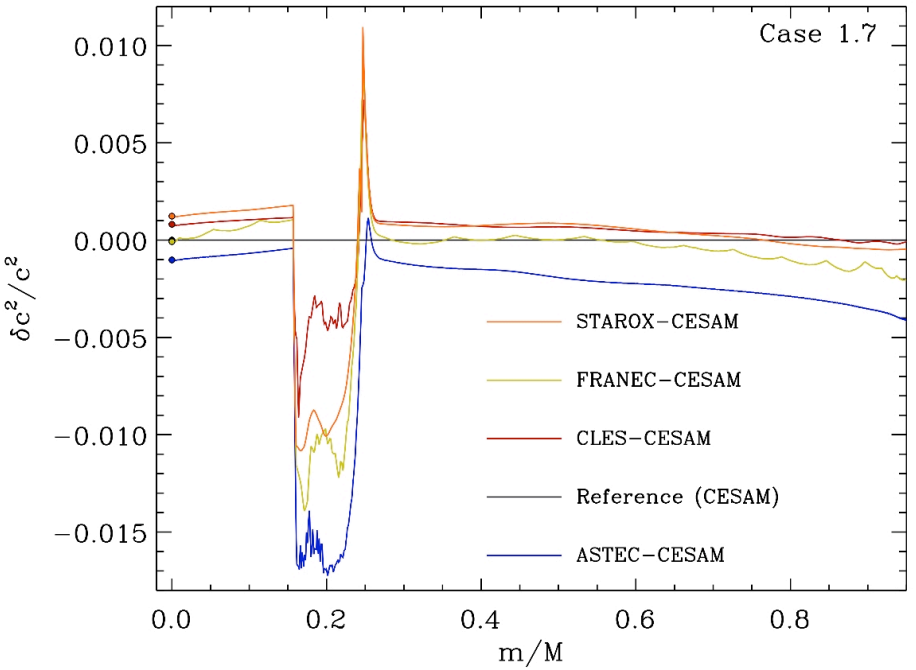
Main sequence (ZAMS) model:

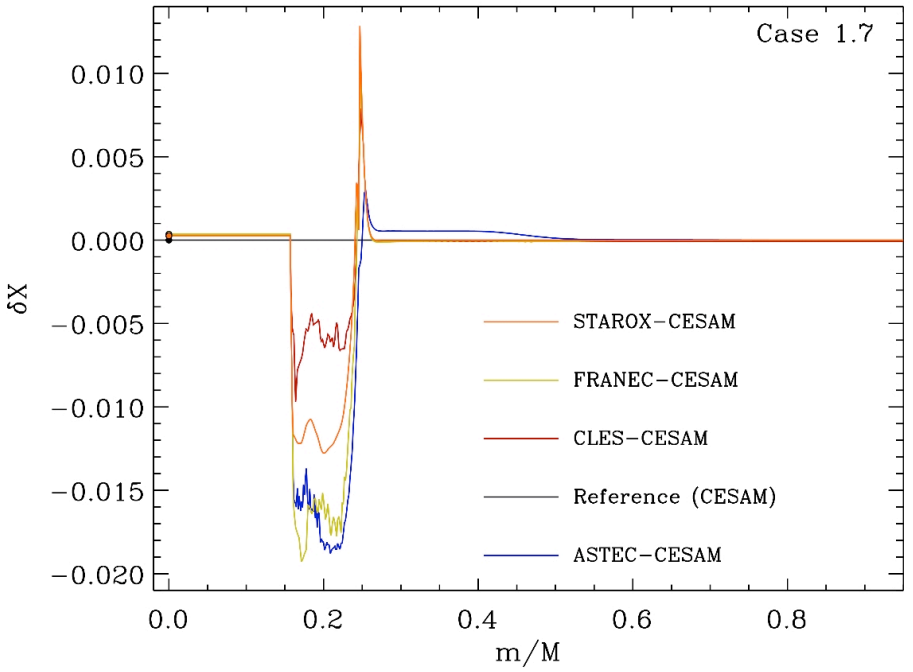
M = 3.0 $M_\odot$

Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
ASTEC	13.32	1.8588	101.52	13 451	2.4834	42.937
CESAM0	14.47	1.8539	101.41	13 466	2.4859	43.043
CLES	14.76	1.8526	101.54	13 475	2.4860	43.021
FRANEC	14.86	1.8590	101.70	13 440	2.4810	42.880
GENEC	14.77	1.8560	100.40	13 423	2.4880	42.600
STAROX	14.46	1.8552	101.64	13 468	2.4872	43.166
Spread (%)	10.9%	0.3%	1.3%	0.4%	0.3%	1.3%
	10.3%	0.3%	0.2%	0.2%	0.2%	0.5%

Case 1.7







Main sequence model:

M = 5.0 $M_\odot$

Code	Age	R/Rsun	L/Lsun	Teff	Tc/10^7	rhoc
ASTEC	56.37	3.8888	746.09	15 312	2.8321	19.600
CESAM0	55.94	3.8539	739.62	15 348	2.8358	19.760
CLES	56.53	3.8622	741.06	15 339	2.8374	19.777
FRANEC	56.86	3.8750	748.20	15 332	2.8360	19.730
GENEC	52.74	3.7340	703.20	15 395	2.8650	19.520
STAROX	55.60	3.8708	744.95	15 342	2.8384	19.761
Spread (%)	7.5%	4.1%	6.2%	0.5%	1.2%	1.3%
	1.7%	0.9%	0.9%	0.2%	0.2%	0.9%

Comparison - internal structure

Results for the comparison of the internal structure (no near-surface layers and atmosphere) for $m<0.95M$:

Δ_{max}	δX	$\delta c^2/c^2$
1.1 ($0.9M_\odot$, MS)	0.0015	0.0025
1.2 ($1.2M_\odot$, ZAMS)	0.0011	0.0026
1.3 ($1.2M_\odot$, PostMS)	0.011	0.0063
1.4 ($2M_\odot$, PreMS)	0.00034	0.004
1.5 ($2M_\odot$, TAMS)	0.08	0.06
1.6 ($3M_\odot$, ZAMS)	0.0075	0.0078
1.7 ($5M_\odot$, MS)	0.019	0.018

Most evident problems:

- edge of convective regions (and in particular when there is overshoot and/or semi-convection)
- near-surface layers and atmosphere

Further steps for the comparison

Some of the aspects of the comparison that should be discussed further are:

- the **initial model**
  - if starting from the near MS define what model that is.
  - if starting from the PMS specify what to use for the initial model.
  - define ZAMS and use it as THE reference for the age (needed for a more detailed test on how the age of a star is determined).
- the **numerics**
  - timestep - what should this be in each evolution phase?
  - mesh - the distribution of the mesh points affects the evolution and in particular at borders of convective zones: how should we deal with it?
- etc...

Exchange of data

In order of facilitate the exchange of models all data for Task 1 is available at the following *anonymous* ftp server:

ftp://ftp.astro.up.pt/pub/users/mjm/task_1/

The directory structure is:

astec/	**cesam1/**	**franec/**	**tgec/**
aton/	**cesam2/**	**genec/**	**yrec/**
cesam0/	**cles/**	**starox/**	

Each directory contains the following folders:

models	- all model files (in different formats)
evolution	- evolutionary sequences
comparison	- tables used in the comparison
freqs	- frequencies and frequency separations
results	- specific results for this code
documents	- information on the code and its results

Conversion tool

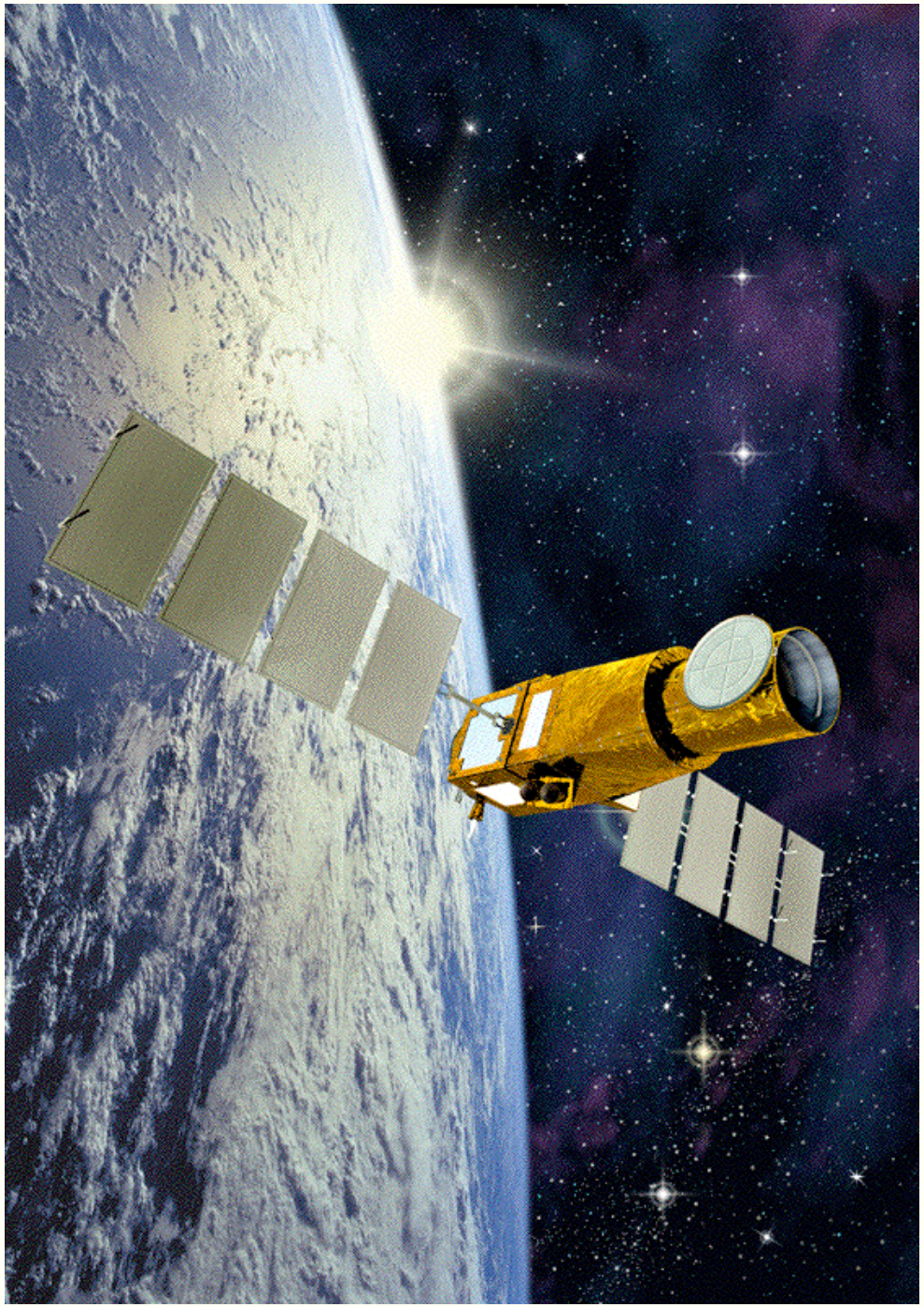
In order of facilitate the comparison and exchange of models a conversion tool has been implemented: **MODCONV**. The objective is to include all formats used within ESTA for producing models and as input for the oscillation codes. More formats will be added as necessary.

The conversions already available are:

[12]	GONG	-|FGONG	[23]	FGONG	-|OSC	[32]	OSC	-|FGONG
[13]		|OSC	[24]		|AMDL	[34]		|AMDL
[14]		|AMDL	[25]		|FAMDL	[35]		|FAMDL
[15]		|FAMDL	[26]		|SROX	[36]		|SROX
[45]	AMDL	-|FAMDL	[62]	SROX	-|FGONG			
[54]	FAMDL	-|AMDL	[64]		|AMDL			
			[65]		|FAMDL			

The possibility to re-mesh the models when formatting the input for the oscillation codes is also being added (the way to do it requires further discussion and tests!).

The end (for now...)



All information about ESTA (data, documents, results, publications, etc) are made available at:

www.astro.up.pt/corot/

If you have suggestions, data, information, documents, etc, relevant for ESTA please contact me at:

mjm@astro.up.pt

A list of publications on topics relevant for ESTA Tasks will also be made available. Please send any suggestions for additions.