Seismology Working Group

Evolution and Seismic Tools Activity

Overview of present status and expectations for model comparison

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ESTA - model comparison

ESTA aims at contributing towards the preparation and exploration of the scientific results of CoRoT. In order to achieve this, the goals set for ESTA include:

- to extensively **test, compare and optimize numerical tools** used to calculate stellar models.

The adopted strategy up to now (to be revised if necessary!) has been:

- To make **as much information as possible available** on the evolution codes and their output,

- To **initiate coordinated activities**, to support the development of the codes and the discussion on the physical assumptions and numerical implementations used in these codes, by:
  - setting specific tasks,
  - facilitating the exchange of data,
  - fostering new collaborations.

Short and long term objectives

CoRoT:

The ultimate goal for CoRoT is to secure that the uncertainties/errors in the models correspond to uncertainties in the frequencies below the expected observational precision. ESTA was setup under the *Seismology Working Group* of CoRoT to secure that the interpretation of the data is solely determined by the physics being used.

Beyond CoRoT:

The exercise under way directed at the CoRoT objectives can and will be extended beyond the needs of a specific mission as the precision of the modelling of stellar structure and evolution is relevant to other projects (space and ground based) as well as to other fields (besides Asteroseismology).

The effort will be extended to a larger community under the support of the European Commission through the **European Network in Helio- and Astero-Seismology** (HELAS) starting in 2006.

ESTA participating codes

ASTEC:
Michael Bazot
Joergen Christensen-Dalsgaard
Maria Pia di Mauro
Teresa C. Teixeira

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

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

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

GARSTEC:
Achim Weiss

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.

ATON and **Geneva** are expected to join Task 1.

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.

Initial work

Liège (2002):

A proposal on the comparison of numerical tools was presented. The need for model and frequency comparisons has been discussed.

In particular it has been referred that aspects as the EOS, opacities, boundaries of convective regions and the atmosphere should be some of the priorities for the comparison.

A preliminary identification of who would participate and what tools could be included in such an effort was achieved.

Granada (2004):

ESTA was effectively setup and a detailed discussion was initiated on what should be the objectives and priorities of the activity. For the comparison of models the standard physics and ingredients to be used were defined. It was further agreed that the first step of the comparison should focus on specific stellar cases. These should be representative of the stellar types in the region of the HR diagram relevant for CoRoT.

As a result the webpage for ESTA was created and Task 1 has been initiated.

Model Comparison: 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 was expected to address **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 <u>global stellar parameters</u> of the selected models and their <u>interior structure are compared</u>. Clues on what are the sources of problems and what items should be further analyzed were the the first results to be expected.

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

Targets

Seven specific **fully identified stellar cases**: representative range in stellar masses, ages and composition.

Case	$M/M_\odot$	Y_0	Z_0	X_C	T_C	$M_{He,cor}$	α_{OV}	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	-	-	-	-	preMS
1.5	2.0	0.26	0.02	0.01	$1.9\ 10^7$	-	0.15	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 $X<0.01$

Preliminary results

Toulouse (2005):

The first/preliminary results on Task 1 obtained with 5 codes were presented as a poster and discussed at a thematic session during the *CoRoT Week 8*. The outcome of this meeting was:

- In order to clarify some of the numerical difficulties it has been proposed to **simplify the physics of the models as much as possible** in order to be sure that the physics we are using is the same.

- After a discussion on how overshoot is implemented in the codes it become clear that it is difficult to compare models with overshoot because the differences may be dominated by **the use of different formulations/implementations of the temperature stratification in the overshoot regions**.

- One of the expected outcomes of Task 1 is the **need to compare evolutionary tracks** and not only models at a specific age. It has been agreed that we should try to compare how the structure evolves for some of the targets starting at the ZAMS, **by selecting specific values of *Xc*** at which the full structure of the models will be compared.

• There is a very important aspect to be discussed further: **what are "acceptable differences" in the global parameters and in the model differences between different codes**. This definition may not be easy/definite but it has been agreed that it is necessary to clarify what are the limits for considering that two models are consistent.

• It has been noted that **a more detailed analysis is required on how convective borders are treated** in both space and time integrations. This seems to be the origin of some of the significant differences between codes found in Task 1.

• It has been argued that it is important for the model comparison effort that a **publication on the reference grids and the comparison** of these with other grids is prepared and published as soon as possible.

• A point has been raised on the need to **look more carefully to the time step used for the main sequence evolution and its effect on the value of *Xc***. A detailed comparison should be prepared on how different prescription for the time step affect the way *Xc* changes with age.

Nice (2005):

Updated results for Task 1 have been presented for 6 codes, mainly resulting from a better match of the reference physics.

$\Delta_{max\text{-}min}$ (%)	age	$R/R_\odot$	$L/L_\odot$	T_{eff}	$T_c/10^7$	ρ_c	R_{env}/R
1.1 ($0.9M_\odot$, MS)	5.0	2.2	4.4	1.5	1.2	2.5	1.0
1.2 ($1.2M_\odot$, ZAMS)	3.0	3.1	4.5	2.0	0.9	2.1	2.7
1.3 ($1.2M_\odot$, PostMS)	7.5	5.0	5.0	1.7	1.0	5.1	2.7
1.4 ($2M_\odot$, PreMS)	19.9	0.9	7.5	0.8	0.2	6.6	0.7
1.5 ($2M_\odot$, TAMS)	3.0	3.1	3.3	2.6	0.6	1.4	0.4
1.6 ($3M_\odot$, ZAMS)	8.3	0.6	3.0	0.6	0.4	1.6	0.5
1.7 ($5M_\odot$, MS)	3.8	1.4	4.3	0.7	0.5	1.4	0.7

Results for the comparison of the internal structure (excluding the atmosphere):

$\Delta_{max-min}$ (%)	$\delta X/X$	$\delta c^2/c^2$
1.1 ($0.9M_\odot$, MS)	**1.7**	**1.0**
1.2 ($1.2M_\odot$, ZAMS)	**0.6**	**0.13**
1.3 ($1.2M_\odot$, PostMS)	**5.0**	**1.2**
1.4 ($2M_\odot$, PreMS)	**0.16**	**1.0**
1.5 ($2M_\odot$, TAMS)	**48.0**	**6.0**
1.6 ($3M_\odot$, ZAMS)	**5.0**	**0.6**
1.7 ($5M_\odot$, MS)	**11.0**	**2.4**

Most evident problems:

- edge of convective regions (evolved models)
- atmosphere (all models)
- nuclear reactions (specific elements and pre-MS models)

Outcome of Nice

Some points requiring further analysis have been identified. Some of these are:

- Some **aspects of the physics require further clarification**,
- It is necessary to **evaluate the effect of the mesh and the time step** in each code,
- **Eliminate remaining evident differences in the physics**,
- Evaluate the **effect of the interpolation in the EoS**,
- **Compare the whole sequence of evolution** for each target.

Results on detailed comparisons between two codes (CESAM and CLES) at specific values of *Xc* for the evolutionary sequence leading to Case 1.5 have also been presented by Montalban & Lebreton showing that models are fairly consistent but there are still some discrepancies requiring further analysis.

Further specification of the physics

The aspects of the physics that need further clarification, to be discussed/implemented during the workshop if possible, are:

- the **equation of state**:
  - which thermodynamic variables should be used?
    - *agree on what is the best option and what to do with the codes.*
  - what interpolation routine?
    - *agree on how the interpolation should be done and how to implement it.*
- the **opacity tables** :
  - tables being used
    - *compare models without conductive opacities*
    - *compare what and how tables are used by the code (interpolation and smoothing)*
    - *check the transition between low temperature and interior opacities*

- What **reference values** are/should be used?
  - atomic masses

    - verify that opacity tables are generated with OPAL atomic masses

    - verify that all codes use the same values as in NACRE

  - mixture

    - verify if the codes use the same values for relative abundances - by specifying what is meant by Grevesse & Noels (1993)

  - isotopes ratio

    - specify the values to be used in all codes

- The **nuclear reactions**
  - network

    - specify the network of reactions to be used and the abundances to follow

    - define precisely what is used for the energy release of the network

- screening

  - *specify precisely what screening is used - it may be useful to compare models calculated without screening*

- What is used for **convection and overshooting**?
  - mixing length theory (MLT)

    - *it is convenient to use the same formulation having the same convective flux (or temperature gradient) everywhere if the mixing length parameter is the same (in particular at the superadiabatic layer)*

  - overshooting

    - *for the comparison try to implement in all codes an option for the temperature gradient that can be compare (either adiabatic or radiative overshoot?)*

    - *some reflection is also necessary on how the extent is specified for the comparison*

- What is use for the **atmosphere**?
  - Eddington's grey atmosphere

    - *use precisely the same $T(\tau)$ relation and the value where the surface ($T=T_{eff}$) is located*

    - *agree on the limit to use for τ (top of the atmosphere)*

    - *specify at what value of τ the atmosphere is matched to the interior*

- **Anything else**?

We are here to find out what else of the physics needs/must be specified to complete Task 1!

Further steps for the comparison

Some of the aspects of the comparison that should also be discussed here, if possible 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
    - **Proposal for defining ZAMS**: when the energy produced by the nuclear network is 99% of the stellar luminosity
- the **numerics**
  - timestep - what should this be in each evolution phase? Test the effect it has in the precision of the result.
  - mesh - the distribution of the mesh points affects the evolution (as in borders of convective zones): how should we deal with it?

While some of the **features** to be compared could be:

- for the oscillations we need to find the best way to provide the **derivative of the density** - it should be compared (or the Brunt-Vaissala frequency)

- compare the **global properties for the full evolutionary sequence** (at fixed values of X_c) of all MS and PostMS cases in Task 1

- compare the **interior structure of Cases 1.5** (done for CESAM-CLES) **and 1.3** at specific values of X_c

- look at the **mesh points at the border of a convective core** (Case 1.3, perhaps) and how those evolve with time.

- and a few more…

…to be selected here as the work progresses!

Support material

Some documents already available that can be useful for the work to be done here are:

- **Descriptions of the codes**
  - Documented at website: CESAM
  - Nice Workshop: ASTEC, CESAM, CLES, FRANEC, TGEC, STAROX
  - Aarhus Workshop: see programme!

- **ESTA reports**
  - "*Report on the CoRoT/ESTA Thematic Session*" (2005-05-25)
  - "*ESTA Roadmap: Who does what and when?*" (2005-09-27)
  - "*CoRoT/ESTA Task 1 - Roadmap for CoRoT Week 9*" (2005-10-20)

- **ESTA documents**
  - "*Description of the File Formats used within CoRoT/ESTA*" (2005-10-20)

- **Task 1 results**
  - "*Task 1 results and implications: what needs to be done and how?*" (2005-10-27)
  - "*CoRoT/ESTA Task 1 - Models comparison preliminary results*" (2005-05-25)

Conversion tool

In order of facilitate the comparison and exchange of models a conversion tool is being 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                         [36]      |STAROX

[45] AMDL   -|FAMDL   [64] STAROX -|AMDL
[54] FAMDL -|AMDL     [65]         |FAMDL
```

The possibility to re-mesh the models when formatting the input for the oscillation codes is also being added.

Exchange of data for Task 1

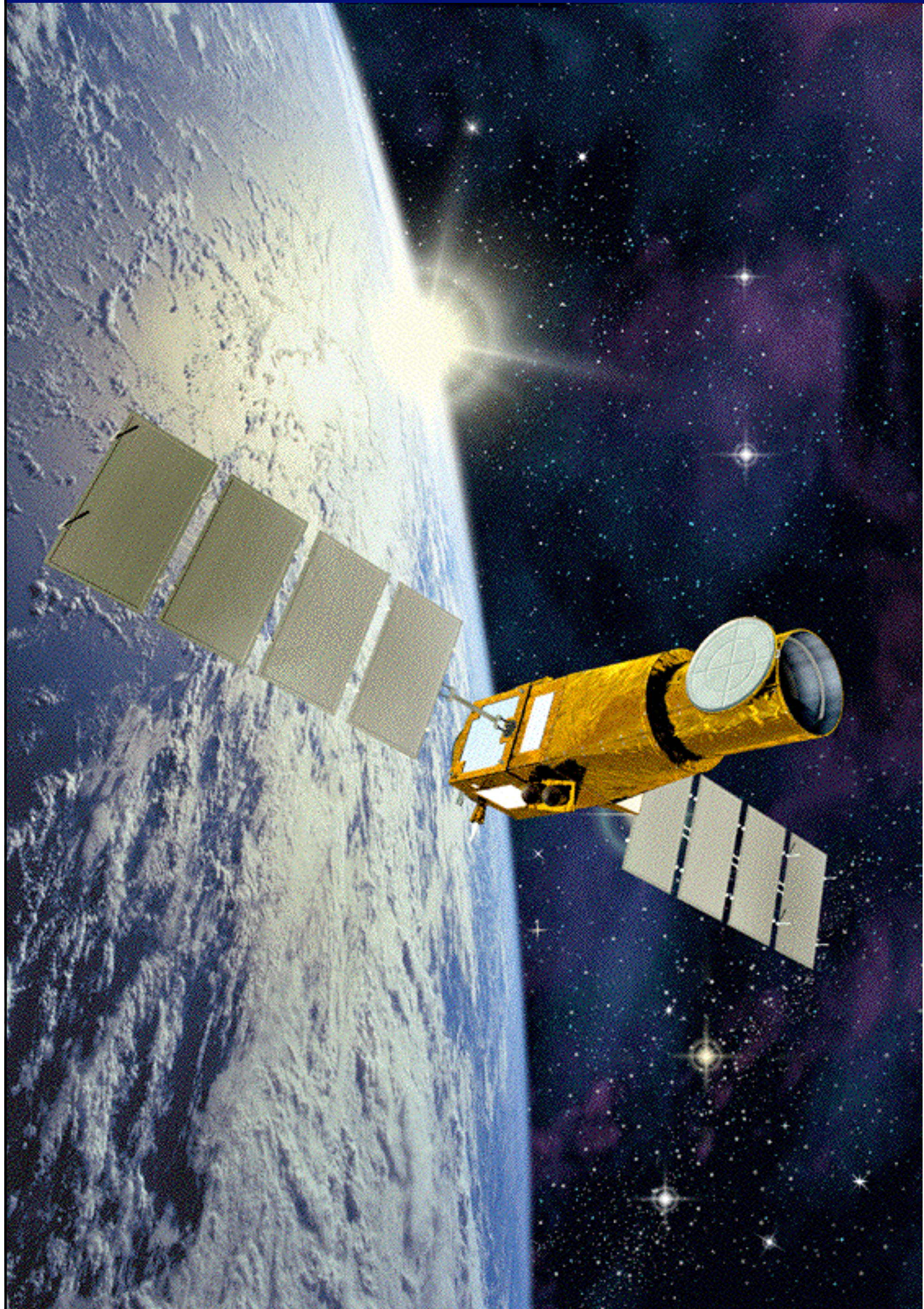
In order of facilitate the exchange of models all data will be available to Task 1 participants in the following url

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

As we progress new updates and new sets of models will be made available here.

The directory structure is:

astec/ **cles/** **res_nice/** **tgec/**
cesam0/ **figs/** **res_toulouse/**
cesam1/ **franec/** **starox/**



Information about ESTA is made available at:

www.astro.up.pt/corot/

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

mjm@astro.up.pt

New initiatives that can complement and/or extend the present activities are welcome!

Now lets do the real work...