

CoRoT/ESTA Task 1

ROADMAP FOR COROT WEEK 9

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Summary

The objective of this document is to provide a guide/roadmap of the work to be developed in order to complete **Task 1** of *CoRoT/ESTA*.

In order to achieve this a detailed list of points/items to be examined by the participating groups in Task 1 is proposed. It is also intended as a further step in clarifying the physics that should be adopted in the comparison in order to remove any known source of discrepancies between different codes.

The items listed here are intended as a guide to the work to be developed up to the next *CoRoT Week* in December 2005. The set of proposed activities/items will be updated if needed as the work progresses. An update is expected after analysis of the results obtained during the *Aarhus Workshop*.

1 Equation of state

1.1 Best choice for the thermodynamic variables and interpolation scheme

Investigate what would be the best choice for the thermodynamic variables and interpolation scheme. In particular it is necessary to define if the thermodynamic derivatives should be taken from interpolation of the tabulated values or from the derivatives of the interpolated procedure adopted for p and u (for example). Progress is expected on this item during the Aarhus meeting from discussions with Werner Däppen.

The consistency of the 2001 Tables should be checked (there are missentries and other questions which have not been corrected yet).

2 Opacity

2.1 Conductive opacities

As a first step models calculated without conductive opacities should be compared.

2.2 Compare OPAL opacity tables

At this stage the simplest would probably be to compare the values of opacities at table points - i.e. values of $(\log R, T_6)$, where $T_6 \equiv T/10^6$ and $R \equiv \rho/T_6^3$, chosen by the OPAL group.

The differences between the raw tables and the values obtained using the OPAL smoothing routine (after Seaton) should be looked at.

2.3 Compare the atomic masses

Clarify what tables have been implemented in the codes. In particular if they have been obtained directly from the OPAL group or generated from the OPAL site.

If the tables are generated by the user from the OPAL site, the values of the atomic masses used in evolution codes should be compared with the values used by the OPAL group. The atomic masses $m(i)$ adopted by the OPAL group are the following.

H:	$m(1)=1.0079d0$	He:	$m(2)=4.0026d0$	Li:	$m(3)=6.941d0$
Be:	$m(4)=9.0122d0$	B:	$m(5)=10.811d0$	C:	$m(6)=12.011d0$
N:	$m(7)=14.0067d0$	O:	$m(8)=15.9994d0$	F:	$m(9)=18.9984d0$
Ne:	$m(10)=20.179d0$	Na:	$m(11)=22.98977d0$	Mg:	$m(12)=24.305d0$
Al:	$m(13)=26.98154d0$	Si:	$m(14)=28.0855d0$	P:	$m(15)=30.97376d0$
S:	$m(16)=32.06d0$	Cl:	$m(17)=35.453d0$	Ar:	$m(18)=39.948d0$
K:	$m(19)=39.0983d0$	Ca:	$m(20)=40.08d0$	Sc:	$m(21)=44.956d0$
Ti:	$m(22)=47.90d0$	V:	$m(23)=50.9414d0$	Cr:	$m(24)=51.996d0$
Mn:	$m(25)=54.938d0$	Fe:	$m(26)=55.847d0$	Co:	$m(27)=58.9332d0$
Ni:	$m(28)=58.7d0$				

According to R. Scuflaire there is an error in the Ar mass.

2.4 Transition between different opacity regimes

Test with the same evolution code two sets of opacity tables where OPAL and AF have been merged differently.

2.5 Interpolation methods

Test different interpolation schemes using the same code (preferably).

3 Mixture

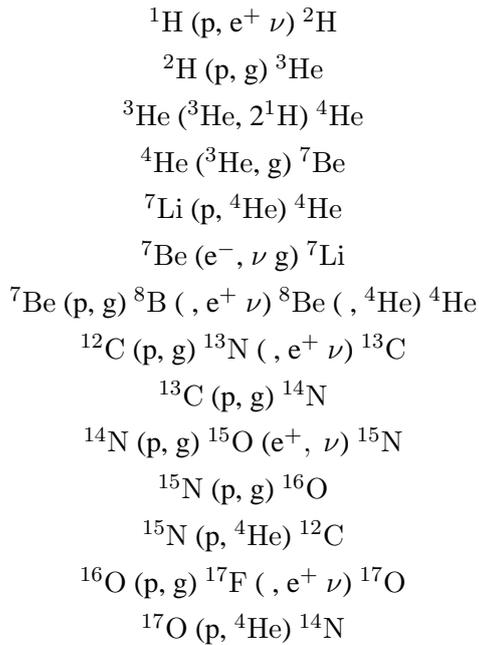
Verify if the Grevesse & Noels (1993) mixture used in evolution codes is consistent. For instance the Grevesse and Noels solar mixture (as implemented in CESAM) is the following [ab(i) states for $\log N$ (N number)]:

ab(1)=12.00d0	ab(2)=10.99d0	ab(3)=1.16d0
ab(4)=1.15d0	ab(5)=2.60d0	ab(6)=8.55d0
ab(7)=7.97d0	ab(8)=8.87d0	ab(9)=4.56d0
ab(10)=8.08d0	ab(11)=6.33d0	ab(12)=7.58d0
ab(13)=6.47d0	ab(14)=7.55d0	ab(15)=5.45d0
ab(16)=7.21d0	ab(17)=5.5d0	ab(18)=6.52d0
ab(19)=5.12d0	ab(20)=6.36d0	ab(21)=3.17d0
ab(22)=5.02d0	ab(23)=4.d0	ab(24)=5.67d0
ab(25)=5.39d0	ab(26)=7.5d0	ab(27)=4.92d0
ab(28)=6.25d0		

4 Nuclear reaction rates

4.1 The network

All codes should try to use the same network of reactions. In CESAM the network used is the following:



For ${}^7\text{Be}$ it is used the formula (26) given in Adelberger et al. (1998) who follows Bahcall & Pinsonneault (1969).

As a reference it is proposed that all codes involved in the comparison use the analytical fits provided by NACRE. The values used for energy release from the reaction network should be compared - this is not complete in the NACRE library as one needs to add in the β decays and subtract neutrino losses. The same energy release factors should be used.

4.2 Abundances

Follow explicitly the same elements. As the reference the abundances of the following elements should be followed by the codes:

- ${}^1\text{H}$, ${}^3\text{He}$, ${}^4\text{He}$, ${}^{12}\text{C}$, ${}^{13}\text{C}$, ${}^{14}\text{N}$, ${}^{15}\text{N}$, ${}^{16}\text{O}$, ${}^{17}\text{O}$ - for models on the main sequence
- ${}^2\text{H}$, ${}^7\text{Li}$, ${}^7\text{Be}$ - to be added to the previous list for pre-main sequence models

4.3 Screening

Models calculated without screening should be compared.

It is also necessary to check the screening formulae implemented in each code and to describe how the number of free electrons is determined. One option is to adopt the screening of Salpeter (1954), with the expressions (4-215) and (4-221) given in Clayton (1968):

$$f = \exp \left(0.188 z_1 z_2 \sqrt{\frac{\rho \zeta}{T_6^3}} \right) \quad \text{where} \quad \zeta = \sum_i z_i (1 + z_i) x_i .$$

Here z_i is the charge of nucleus i and x_i the abundance per mole of the i element.

4.4 Nuclear data, initial abundances and isotopes.

The masses (in amu) of the nuclei should be taken from NACRE 1999, corresponding to the following values:

$^1\text{H} = 1.00782500\text{E}+00$	$^2\text{H} = 2.01410180\text{E}+00$	
$^3\text{He} = 3.01602930\text{E}+00$	$^4\text{He} = 4.00260330\text{E}+00$	
$^6\text{Li} = 7.01600400\text{E}+00$	$^7\text{Li} = 6.01512100\text{E}+00$	
$^7\text{Be} = 7.01692920\text{E}+00$	$^9\text{Be} = 9.01218210\text{E}+00$	
$^{12}\text{C} = 1.20000000\text{E}+01$	$^{13}\text{C} = 1.30033548\text{E}+01$	
$^{13}\text{N} = 1.30057386\text{E}+01$	$^{14}\text{N} = 1.40030740\text{E}+01$	$^{15}\text{N} = 1.50010890\text{E}+01$
$^{16}\text{O} = 1.59949146\text{E}+01$	$^{17}\text{O} = 1.69991315\text{E}+01$	
Neutron = 1.00866500E+00	Proton = 1.00727647E+00	

The same initial relative abundances should be used for isotopes. In CESAM the isotopic ratios of Anders & Grevesse (1989) are used, except for $^3\text{He}/^4\text{He}$ where it is taken the value from Gautier & Morel (1997). The values, as number fractions, are:

$^2\text{H}/^1\text{H} = 3.010\text{E}-05$	$^3\text{He}/^4\text{He} = 1.100\text{E}-04$	
$^6\text{Li}/^7\text{Li} = 8.108\text{E}-02$	$^7\text{Be}/^9\text{Be} = 1.000\text{E}-25$	$^{13}\text{C}/^{12}\text{C} = 1.112\text{E}-02$
$^{15}\text{N}/^{14}\text{N} = 3.673\text{E}-03$	$^{16}\text{O}/^{17}\text{O} = 3.809\text{E}-04$	$^{22}\text{Ne}/^{20}\text{Ne} = 7.302\text{E}-02$
$^{25}\text{Mg}/^{24}\text{Mg} = 1.266\text{E}-01$	$^{26}\text{Mg}/^{25}\text{Mg} = 1.101\text{E}+00$	$^7\text{Be}/\text{Z} = 1.000\text{E}-29$

5 Convection and overshooting

5.1 Formulation of the MLT

It is necessary to identify if different codes use different formulations of the MLT. If possible all implementations should be consistent.

5.2 Value of the mixing-length

Study the effects of the value of the mixing-length adopted in the regions close to convection zone limits.

5.3 Temperature gradient in the overshooting zone

Compare models with the same choice of temperature stratification in the overshooting zone. As the reference it should be adopt either adiabatic stratification ($\nabla_{\text{ov}} \equiv \nabla_{\text{ad}}$) or radiative stratification ($\nabla_{\text{ov}} \equiv \nabla_{\text{rad}}$) for the overshoot layer.

6 Atmosphere

6.1 External boundary condition

Adopt the same model for the atmosphere. As a reference we propose the grey atmosphere using the Eddington $T(\tau)$ relation:

$$T^4 = \frac{3}{4} T_{\text{eff}}^4 \left(\tau + \frac{2}{3} \right)$$

The bottom of the atmosphere ($T=T_{\text{eff}}$) corresponds to $\tau=2/3$, where $r=R$ is the photospheric radius.

6.2 Connecting the atmosphere with the envelope

Study the effects of connecting the atmosphere with the envelope at different optical depth.

7 Initial conditions

7.1 Initial model of the sequence

Compare models beginning the evolution on the ZAMS with models including the PMS evolution. Check in particular the chemical profile of key elements and the values at the centre for the models. What is used as the initial PMS model also requires identification.

In order to do use the ZAMS as a reference point in the evolution it is necessary to agree on a common definition of what is meant by ZAMS.

8 Precision

8.1 Time steps

Compare models calculated with the same parameters and code but using different time steps. Compare also models calculated with different codes but using similar time steps.

8.2 Mesh points

The repartition of the mesh points will probably be somewhat different, but models calculated with different codes and using similar number of mesh points should be compared.

Also, with the same code models calculated with different number of mesh points should also be compared.

8.3 Numerical formulation of the equations

The effect on the result of the form of the equations being solved - the variables being used (r, L, T, ρ) or (r, L, T, P) or log of the variables including $\log M$ or some other combination - should be estimated. Different forms of the equations will give somewhat different results. This is a measure of the accuracy of the solution.

Similarly the form of the chemical equations used and the solution scheme should also be study. First order implicit differences have many representations - some subdivide the time step to advance the chemistry using a much smaller time step than is used for advancing the structure. The implications on the precision of the solution can vary.

9 Features to be compared

These are some possibilities to consider. The need to compare other output quantities will become clear as we proceed with the comparisons, in particular during the *Aarhus Workshop*.

9.1 Brunt-Väisälä frequency

Compare for the existing Task 1 cases the following quantity:

$$\frac{1}{\Gamma_1} \frac{d \log p}{d \log r} - \frac{d \log \rho}{d \log r}.$$

9.2 Evolutionary tracks in the HRD

Compare the full evolutionary sequences (at fixed values of X_c) for all cases addressed in **Task 1**.

9.3 Interior at particular evolution stages

Compare for the same stellar cases the structure of the interior at particular evolutionary stages of the sequence for **Cases 1.3** and **1.5**. Specific stages are identified by the central value of X corresponding to:

$$X_c = 0.70, 0.60, 0.50, 0.40, 0.20, 0.10, 0.05 \text{ and } 0.01 .$$

9.4 Evolution with time of convective borders

Follow in time the size of the convective core and/or depth of a convective envelope at different stellar parameters as given by different codes.

References

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