

# Guidelines for the Implementation of Different Dark Energy Models in CLASS

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In order to implement different dark energy models one should modify the CLASS package as follows<sup>1</sup>:

- Calculate  $w(a)$  as well as  $w'(a)$  (its derivative with respect to the scale factor  $a$ ). We need to consider the scale factor, since all the DE models implemented in class use the scale factor. Furthermore the form of  $f_{DE} \equiv -3 \int_1^a \frac{1+w(a')}{a'} da'$  is also needed. All these quantities should be written in C format.
- Download the latest version of CLASS from [the official github repository](#).
- Class has already implemented some basic DE models. In particular, in the `explanatory.ini` file in the section 8a entitled “Dark energy contributions” (line 165) we can find all the relevant information regarding DE. The three models already implemented are the following:
  - $\Lambda$ CDM corresponding to `Omega_Lambda` in line 175.
  - CPL corresponding to `Omega_fld` in line 176.
  - Scalar Field corresponding to `Omega_scf` in line 177. In this case, the Klein Gordon equation is solved for a scalar field.

Basically we need to set the values of each case according to the DE model we want to study. In particular, for a DE model we need to fix two out of three parameters to zero and leave the third one unspecified in order to be calculated by CLASS. For example, if we want a specific DE model, we need to set `Omega_Lambda=0` (in order to have zero cosmological constant), `Omega_scf=0` (in order to avoid any contribution from the scalar field) and choose `Omega_fld` to be unspecified, i.e. `#Omega_fld`. As a result, the considered model will be the CPL, thus a simple way of implementing a new DE model is to redefine the CPL model to the form of the DE we want.

- You may also need to change the `use_ppf` command in the `explanatory.ini` file in line 187. The default option is yes in order to allow the perturbations to cross the phantom divide.
- The main files that we also need to modify, are the `input.c` file in order to define the parameters of the DE model and in the `background.c` file where we will change the CPL model to the specified DE model. Both of these files are inside the `source` folder. Before we insert the parameter in the `input.c` file we also need to define the parameters type inside the include folder and in particular in the appropriate header file (.h). Since we just need to modify the background, we go to the `background.h` file. In particular, what we need to do is the following:
  - In the `background.h` file, we can find all the background parameters that are listed. So, at first we need to define inside the struct background (line 35) loop, the type of the variables of the DE model (*e.g.* double, float etc.) with some relevant comments.
  - Next we need to modify the file `background.c`. Depending on the form of the DE model, we may need to include some extra libraries (*e.g.* `#include <stdio.h>`) in the beginning of the file (*e.g.* in line 81, below the `#include "background.h"` command). Then, we need to modify lines 534, 569 as well as 592 where we substitute the functions `*w_fld`, `*dw_over_da_fld` and `*integral_fld` with the forms of  $w(a)$ ,  $w'(a)$  and  $f_{DE}$  respectively. It is important to note here, that the three functions  $w(a)$ ,  $w'(a)$  and  $f_{DE}$  should be written in C form and the parameters of our model should have the form `pba→name_of_the_variable`, where the acronym pba stands for background parameter.

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<sup>1</sup> The line numbers correspond to the latest versions of the relevant files at the time this document was written, even if they are changed in newer versions one should get the general idea.

- Finally in the `input.c` file, in line 1372 we need to include inside the `if (pba->fluid_equation_of_state == CLP)` routine of the DE variables such as: `class_read_double("name_of_the_variable",pba->name_of_the_variable);` and somewhere between lines 3176 and 3467, *i.e.* inside the `/** - background structure */` the default values of the extra parameters of the DE model.
- After that you are good to go. Just type in the terminal the `make clean` and `make` commands!

Good Luck!!