

# **New AlterBBN**

## **A Short User Manual**

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## About AlterBBN

AlterBBN is a public C program written by Alexandre Arbey. Its purpose is to compute the abundances of the light elements predicted by Big Bang Nucleosynthesis (BBN). Different cosmological scenarios are implemented in AlterBBN, which may alter the BBN predictions.

THE ORIGINAL VERSION: The original AlterBBN\_v1.4, which the Master thesis was built on, can be downloaded from the website <https://alterbbn.hepforge.org/>. A new version is currently being developed, with parts from the thesis being included.

THIS VERSION: An update of the original program was developed during the work on my Master thesis at the Institute of Theoretical Astrophysics at the University of Oslo. It has led to a slight re-structuring of the program, as well as the inclusion of generic dark matter candidates to the calculations. The whole, updated AlterBBN can be found at <https://github.com/espensem/AlterBBN>. Worth noting is that this version may differ a bit from the new version currently being developed when it comes to how the code is structured and how it is implemented by the user.

This short manual describes how to use the updated AlterBBN. For a more detailed description of the code, please visit the AlterBBN home-page (link above).

## Overview of Files and Folders

The main directory of AlterBBN contains 3 files and 3 folders. The 3 files are:

- *Makefile* - A customized makefile for compiling the program the desired way.
- *input.ini* - Used to initialize cosmological parameters and other initial values needed to run the program.
- *primary.c* - Main AlterBBN program. Reads the arguments from input.ini.

The 3 folders are:

- *ini\_files/* - Contains a C method for reading *.ini*-files properly.
- *src/* - Contains the AlterBBN source-files (explained below). Two additional files needed for compiling AlterBBN are also found in this folder, as well as the sub-folder *sgStar\_heff*. This sub-folder contains tables of effective degrees of freedom for the temperatures relevant for the AlterBBN calculations, which are collected in *omega.c*.

The AlterBBN source-files are:

- *include.h* - Imports and initialization of routines.
- *general.c* - Mathematical expressions and functions used in the program.
- *omega.c* - Initializer methods and helper methods used in the program.
- *bbnrate.c* - Computes the forward and reverse reaction rates for all nuclear reactions used in AlterBBN.
- *bbn.c* - The engine of AlterBBN. Contains the main routine *nucl* called in *primary.c*.

## User Specified Cosmological Parameters

Through the AlterBBN input-file *input.ini* the user may instantiate different cosmological parameters, as well as the initial temperature ( $T_{9,i}$ ) for the iteration process. Listed below are the different cosmological parameters (parameter name in *input.ini* in parenthesis), sorted by the different **cosmological scenarios** they will affect. The different cosmological scenarios are discussed in section **Cosmological Scenarios**.

Affects **standard**, **darkdens**, **reheating** and **wimp**:

- $\eta$  (eta) - The baryon-to-photon ratio.
- $N_\nu$  (nnu) - The number of standard model (SM) neutrinos.
- $\Delta N_\nu$  (dnnu) - The number of equivalent neutrinos.
- $\tau_n$  (tau) - The mean neutron lifetime.
- $\xi_e$  (xi\_1) - The electron neutrino degeneracy.
- $\xi_\mu$  (xi\_2) - The muon neutrino degeneracy.
- $\xi_\tau$  (xi\_3) - The tau neutrino degeneracy.

Affects **darkdens** and **reheating**:

- $\kappa_\rho$  (dd0) - Ratio of dark energy density over radiation density at BBN time.
- $n_\rho$  (ndd) - Dark energy density decrease exponent.

Affects **darkdens**:

- $\kappa_s$  (sd0) - Ratio of dark entropy density over radiation density at BBN time.
- $n_s$  (nsd) - Dark entropy density decrease exponent.
- $T_\rho$  (Tdend) - Temperature in GeV below which the dark energy density is set to 0.
- $T_s$  (Tsend) - Temperature in GeV below which the dark entropy density is set to 0.

Affects **reheating**:

- $\kappa_\Sigma$  (Sigmad0) - Ratio of dark entropy production over radiation entropy production at BBN time.
- $n_\Sigma$  (nSigmad) - Dark entropy production exponent.
- $T_r$  (TSigmaend) - Temperature in GeV below which the dark energy density and the dark entropy production are set to 0.

Affects **wimp**:

- $m_\chi$  (mass\_wimp) - Mass of light WIMP in MeV.
- (type\_wimp) - Type of WIMP (1, 2, 3, 4) for (real scalar, complex scalar, Majorana fermion or Dirac fermion).
- (coupling) - WIMP coupling to the SM particles (1, 2, 3) for (electromagnetically coupled, SM neutrino coupled, SM and equivalent neutrino coupled).

## Cosmological Scenarios

The new AlterBBN can analyze BBN through five different cosmological scenarios, including relevant combinations of the five. This section discusses these cosmological scenarios, and explains how the AlterBBN input-file *input.ini* should be used in each case.

**Paramfree** may be used for a parameter-free Standard Big Bang Nucleosynthesis (SBBN) scenario. The notion parameter-free comes from the fact that it takes no user specified cosmological parameters to run. Instead, default values for the baryon-to-photon ratio ( $\eta$ ), the number of standard model neutrinos ( $N_\nu$ ), the mean neutron lifetime ( $\tau_n$ ) and the initial temperature ( $T_{9,i}$ ) are used. As new measurements of  $\eta$  and  $\tau_n$  are released in the future, the default values of these parameters should be changed within the method *Init\_cosmomodel* in *omega.c*. In SBBN the number of equivalent neutrinos ( $\Delta N_\nu$ ), as well as any neutrino degeneracy ( $\xi_e/\xi_\mu/\xi_\tau$  for electron/mu/tau neutrino degeneracy) is assumed to be zero.

**Standard** allows for the user to provide values for the cosmological parameters  $\eta$ ,  $N_\nu$ ,  $\Delta N_\nu$ ,  $\tau_n$ ,  $\xi_e$ ,  $\xi_\mu$ ,  $\xi_\tau$  through *input.ini*. This is not the SBBN scenario in its most strict sense. To avoid unnecessary many cosmology type options, the equivalent number of neutrinos and neutrino degeneracy is added to this option. Running strict SBBN scenarios these parameters may simply be set to zero.

**Darkdens** adds an effective dark energy density and/or an effective dark entropy density by setting values for  $\kappa_\rho$ ,  $n_\rho$ ,  $\kappa_s$ ,  $n_s$ ,  $T_\rho$  and  $T_s$  from *input.ini*. All parameters in the **standard** option is instantiated when invoking the **darkdens** option. Setting all the above parameters to zero is similar to running the **standard** option.

**Reheating** adds an effective dark energy density and/or an effective dark entropy production by setting the values for  $\kappa_\rho$ ,  $n_\rho$ ,  $\kappa_\Sigma$ ,  $n_\Sigma$  and  $T_r$  from *input.ini*. All parameters in the **standard** option is instantiated when invoking the **reheating** option. Setting all the above parameters to zero is similar to running the **standard** option.

**Wimp** may be used to add one of four generic WIMP candidates, which are real scalars, complex scalars, Majorana fermions and Dirac fermions. The WIMP's coupling to the SM particles must be specified, as well as its mass,  $m_\chi$ .

## Compilation and Execution

AlterBBN is written for a C compiler respecting the C99 standard, and it has been tested successfully with the GNU C and the Intel C Compilers on Linux and Mac.

Having downloaded and installed the new AlterBBN on your computer, go to the main directory and type

**make**

This creates *libbbn.a* in *src/* and does not have to be repeated later, as long as *libbbn.a* is not removed. To compile the main program *primary.c*, type

**make primary.c**

Editing the source code requires a new compilation of the main program, however, editing the AlterBBN input-file *input.ini* does not. Compiling the main program creates the executable *primary.x*. The program may then be executed with or without input arguments:

**primary.x**

will invoke the **paramfree** option,

**primary.x standard**

will invoke the **standard** option,

**primary.x darkdens**

will invoke the **darkdens** option,

**primary.x reheating**

will invoke the **reheating** option and

**primary.x wimp**

will invoke the **wimp** option.