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, created by Alexandre Arbey, can be downloaded from the website `http://superiso.in2p3.fr/relic/alterbbn/`, along with a user manual.

NEW AND UPDATED VERSION: An update of the original program was developed during the work on this author's 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`.

This short manual describes how to use the updated AlterBBN. For a more detailed explanation of its structure, underlying physics, and how it differs from the original AlterBBN, see the longer manual AlterBBN_manual_LONG.pdf.

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. It also reads the arguments from input.ini.

The 3 folders are:

- Ares/ - A Python program that compiles and executes AlterBBN externally. This is a handy tool if the user wants to run AlterBBN multiple times, varying a cosmological parameter. See section External Tools.
- 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**:

- η (eta) - The baryon-to-photon ratio.
- N_ν (nnu) - The number of standard model (SM) neutrinos.
- ΔN_ν (dnnu) - The number of equivalent neutrinos.
- τ_n (tau) - The mean neutron lifetime.
- ξ_e (xi_1) - The electron neutrino degeneracy.
- ξ_μ (xi_2) - The muon neutrino degeneracy.
- ξ_τ (xi_3) - The tau neutrino degeneracy.

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

- κ_ρ (dd0) - Ratio of dark energy density over radiation density at BBN time.
- n_ρ (ndd) - Dark energy density decrease exponent.

Affects **darkdens**:

- κ_s (sd0) - Ratio of dark entropy density over radiation density at BBN time.
- n_s (nsd) - Dark entropy density decrease exponent.
- T_ρ (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**:

- κ_Σ (Sigmad0) - Ratio of dark entropy production over radiation entropy production at BBN time.
- n_Σ (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_χ (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).

For a physical explanation of the different cosmological parameters, see the extended AlterBBN manual AlterBBN_manual_LONG.pdf.

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 (η), the number of standard model neutrinos (N_ν), the mean neutron lifetime (τ_n) and the initial temperature ($T_{9,i}$) are used. As new measurements of η and τ_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 (ΔN_ν), 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 η, N_ν, ΔN_ν, τ_n, ξ_e, ξ_μ, ξ_τ 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 κ_ρ, n_ρ, κ_s, n_s, T_ρ 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 κ_ρ, n_ρ, κ_Σ, n_Σ and T_r from *imput.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_χ.

For a detailed explanation of the different cosmological scenarios, see the extended AlterBBN manual AlterBBN_manual_LONG.pdf.

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.

External Tools

In many cases we want to analyze the light element abundances for several values of one or more of the cosmological parameters. The most efficient approach to this would be to create internal loops inside AlterBBN. However, to keep AlterBBN and *input.ini* as clean and simple as possible for single runs, and to minimize the need for input arguments, a separate Python program ARES was created to achieve the the same task. ARES interacts with AlterBBN through *input.ini* and the one optional input argument. It may iterate through different values of one of the cosmological parameters by changing its value in *input.ini* and executing AlterBBN for each iteration. Since AlterBBN only need to be compiled once, the loss of efficiency compared to having a loop inside AlterBBN is marginal. It also creates a more flexible way of using AlterBBN, as ARES may be called upon in separate methods to iterate through several cosmological parameters.

ARES can be found at `https://github.com/espensem/AlterBBN` along with a manual for the program.