BBN and a lower bound on the dark matter mass

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1 Introduction

The idea behind this project is very simple. The latest BBN bounds on the dark matter mass were obtained a while ago in [1] and [2].

The values of the primordial nuclei abundances used in those papers are:

$$Ref.\ [1]: \qquad Y_p = 0.249 \pm 0.009 \qquad D/H = (2.81 \pm 0.21) \times 10^{-5}\,, \tag{1}$$

$$Ref.\ [2]: \qquad Y_p = 0.254 \pm 0.003 \qquad D/H = (2.53 \pm 0.04) \times 10^{-5}\,. \tag{2}$$

The current measured abundances, as recommended by the PDG are:

$$Ref.\ [3]: \qquad Y_p = 0.245 \pm 0.003 \qquad D/H = (2.569 \pm 0.027) \times 10^{-5}\,, \tag{3}$$

And therefore, there is potential room for improvement in the constraints. In addition, these analyses are not totally CMB independent. This is because they fixed the baryon abundance of the Universe (which in principle should be left as a free parameter) to be that given by CMB observations. In principle, with the measurement of Y_p and D/H one should obtain a bound on $m_{\rm DM}$ by marginalizing over the baryon abundance of the Universe. Also, the neutron lifetimes determines the output of Y_p and D/H and should also be varied.

In addition, these analyses considered the instantaneous decoupling approximation, that works reasonably well but that may lead to biased results. In [4] an approach to the neutrino decoupling, that includes all relevant effects in a simplified manner, was developed. This can be used to provide an accurate early Universe description of the photon and neutrino temperature in the early Universe that is needed for the computation of the primordial nuclei abundances.

Thus, given the current interest in sub-GeV scale dark matter and the room for improvement that previous studies have left, obtaining BBN and BBN+CMB constraints for the mass of thermal dark matter particles will render relevant constraints for particle physicists.

In addition, several forecast for what constraints can future measurements of the primordial nuclei abundance provide on m. In particular, given that the measured primordial deuterium abundance could potentially be determined with an order of magnitude smaller error in the near future [5].

2 What do we need to do?

What we are lacking is access to a modified version of a BBN code. The two most used codes are PARTHENOPE [6, 7] and AlterBBN [8, 9]. In addition, very recently also PRIMAT [10] appeared in the literature. I believe the easiest to use and modify is AlterBBN. However, AlterBBN is not as precise as Parthenope or PRIMAT. Since Parthenope is in Fortran and is mainly hardcoded, I suggest we try to modify PRIMAT. PRIMAT is a MATHEMATICA code that has been recently developed. Which means that their authors will likely answer many of our questions.

The idea will be to modify PRIMAT in order to include the early Universe evolution in the presence of particles in thermal equilibrium with the SM plasma. This we can easily obtain from my code. And then, once PRIMAT is modified it will just be a matter of analyzing different models accounting for nuclear uncertainties in the reaction rates and making nice tables.

The PRIMAT paper contains a very detailed review of BBN [10]. For a first read review it may be too dense. Other references that I think are useful and more introductory are [11, 12].

PRIMAT can be found in the Dropbox folder.

I think that a more or less logical procedure to actually get the code working are:

1. Understand the physics. How does BBN work? What particles enter in the relevant processes in the SM?

   As a first read I would go with the review [11].

   I would look also at the PDG review [3] in order to understand how the primordial nuclei abundances are measured.

   Write a simple code on your own that calculates Y_p given the neutron lifetime. This can be done with the formulae in [11].

2. Understand the physics. How do WIMPs alter the story? What do they modify?

   I think my paper could be a good starting point [4].

3. Which variables do PRIMAT use for the time evolution? T_γ? Then express my code in their evolution variables.

4. Start modifying and creating a function that allows one to get the primordial nuclei abundances as a function of the mass of a WIMP.

5. Run Monte Carlo analyses to get the bound on m_χ.

6. Investigate how upcoming measurements of the primordial deuterium abundance can help in constraining light thermal WIMPS. The error in D/H could potentially go down by a factor of 10 in the future [5].

References

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