Big Bang Nucleosynthesis

Big Bang Kernesyntese

Hans Brüner Dein
201706079

Master's Thesis in Cosmology
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Supervisor: Thomas Tram

Department of Physics and Astronomy
Aarhus University

Colophon

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— Big Bang Kernesyntese

Master's thesis by Hans. Written under supervision by Asc.Prof. Thomas Tram, Department of Physics and Astronomy, Aarhus University.

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Abstract (English)

Nucleosyntehesis is wack

Resumé (Dansk)

Kernesyntese er spøjs

List of Corrections

Preface

This thesis concludes my Master’s degree in/at .....

Contents

Introduction

This thesis is about nucleosysthesis

Chapter 1

BBN physics and cosmology

To understand the process of Big Bang nucleosynthesis, we must examine the intersection between Cosmology, thermodynamics, particle, and nuclear physics. Though this might seem daunting, it turns out that the unique conditions during this epoch allow for extensive simplifications of this otherwise monumental task.

1.1 Determining background parameters

1.1.1 Temperature and scale factor

BBN takes place after inflation while the universe is still radiation dominated. This can be described by the Friedman equation, which can be further simplified with the reasonable approximation, that both curvature and the cosmological constant are zero.

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho_{tot} \tag{1.1}$$

With ρ_{tot} referring to the total energy density of photons, leptons and baryons.

$$\rho_{tot} = \rho_\gamma + \rho_\nu + (\rho_{e^-} + \rho_{e^+}) + \rho_b \tag{1.2}$$

To find an expression for the temperature evolution, we use energy conservation. We can consider the neutrinos as decoupled during BBN, and so the photon temperature will be determined by the remaining components. Since this point the universe is very much homogeneous and isotropic, we utilize the fluid equation for adiabatic expansion.

$$\dot{\rho_{set}} + 3\frac{\dot{a}}{a}(\rho_{set} + P_{set}) = 0 \tag{1.3}$$

With ρ_{set} being the density of none-decoupled components and P_{set} being their pressures.

$$\rho_{set} = \rho_\gamma + (\rho_{e^-} + \rho_{e^+}) + \rho_b \quad , \quad P_{set} = P_\gamma + (P_{e^-} + P_{e^+}) + P_b \tag{1.4}$$

With this we can set up differential equations describing the time evolution of the scale factor and photon temperature.

$$\frac{dT}{dt} = -3H\frac{\rho_{set}(T,a) + P_{set}(T,a)}{\frac{d\rho_{set}(T,a)}{dT}} \quad , \quad \frac{da}{dt} = a\sqrt{\frac{8\pi G}{3}\rho_{tot}(T,a)} \tag{1.5}$$

1.1.2 Additional parameters

h og ϕ Neutrino temperature?

1.2 Energy densities and pressure

1.2.1 Photons

1.2.2 Neutrinos

1.2.3 Electrons and positrons

1.2.4 Baryons

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1.3 Nuclear reactions

1.3.1 Proton $\leftrightharpoons$ neutron rate

Warning test

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1.4 Initial conditions

CHAPTER 2

BBN code

2.1 History of BBN codes

The concept of Big Bang nucleosynthesis is almost as old as the Big Bang theory itself, with the with it first being proposed in the paper by Alpher, Bethe, and Gamow [1]. This early model used neutron capture and subsequent beta decay as the mechanism for BBN, though its greatest problem was the inability to explain the unusually high abundance of oxygen and carbon in the present universe. And so, it was in large part supplanted by the new theory of stellar nucleosynthesis, as the main explanation for the origin of elements.

During the next decades it became clear that stars could not be the only explanation for the present element abundances, and with the discovery of the CMB in 1965, new attention was brought to the early universe. Only a year later Peebles showed how simple BBN physics could be used to explain the high helium abundance, unaccounted for by stellar nucleosynthesis [2].

In the following years Wagoner created and refined the first proper BBN code, described in a series of defining papers[3][4][5]. With the legacy of this code still heavily influencing the way BBN calculations are performed today.

By the late 80s the Wagoner code was severely outdated. With multiple inefficiencies due to among other things, the fact that it was originally designed to run on punch cards. This inspired Lawrence Kawano to create the now ubiquitous NUC123, colloquially know as the Kawano code. Which set the gold Standard for all future BBN codes.

In current day and age, there exists multiple publicly available BBN codes, and a countless number of private codes. The most well know of these are PArthENoPE spiritual successor to NUC123, AlterBBN, and PRIMAT.

2.2 Structure of BBN codes

The objective of any BBN code is to solve the system of differential equations described in chapter 1.

2.2.1 Wagoner

2.2.2 Kawano

2.2.3 Modern codes

PArthENoPE, AlterBBN, PRIMAT

2.2.4 AlterBBN

AlterBBN is written in c and based on Kawano's NUC123. It maintains the same basic structure and integration method, though it uses natural units for everything but the reaction network. However, they define energy in GeV rather than MeV. What separates AlterBBN for other codes is that as the name implies, it allows the use of alternate cosmological models and parameters. Therefore, this code is especially well suited for testing the effects these alterations have on final abundances. Wot

Chapter 3

Comparison with AlterBBN

CHAPTER 4

Comparison with AlterBBN

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