Physical processes effecting the baryonic matter content of the Universe

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Abstract. We have discussed physical processes effecting the generation of the matter content of the Universe.

First we have studied the processes effecting Big Bang Nucleosynthesis during which the chemical content of the baryonic component of the Universe was produced. We have provided detail numerical analysis of the BBN production of ^{4}He, Y_p, in the presence of $\nu_e \leftrightarrow \nu_s$ neutrino oscillations, effective after electron neutrino decoupling. We have accounted for all known effects of neutrino oscillations on cosmological nucleosyntesis. We have obtained cosmological bounds corresponding to $\delta Y_p/Y_p = 5.2\%$ in correspondance with the recently found higher uncertainty in ^{4}He. Iso-helium contours for $\delta Y_p/Y_p > 5\%$ and population of the ν_s state $\delta N_s = 0; 0.5; 0.7; 0.9$, both for resonant and non-resonant oscillations have been calculated.

Next we have studied the processes effecting the formation of the baryon content of the Universe. We have investigated a baryogenesis model based on Affleck and Dine baryogenesis scenario, Scalar Field Condensate (SFC) baryogenesis model. We have provided precise numerical analysis of the SFC baryogenesis model numerically accounting for the particle creation processes by the time varying scalar field. We have numerically obtained the dependence of the field and baryon charge evolution and their final values on the model's parameters, namely: the gauge coupling constant α, the Hubble constant during inflation H_I, the mass of the field m and the self coupling constants λ_i. We have found the range of the model parameters for which a baryon asymmetry value close to the observed one can be generated.

Key words: BBN, Neutrino oscillations, Scalar Condensate Baryogenesis, Baryon Asymmetry

Introduction

The PhD thesis is dedicated to two attractive subjects in modern cosmology - baryogenesis and the chemical composition of the baryonic component in non-standard BBN with neutrino oscillations.

According to the Standard Cosmological model, the baryon content and the observed baryon asymmetry of the Universe were created after inflation, during a baryogenesis process. There exist observational data on baryon density and the baryon asymmetry of the Universe. There are precise measurements of the baryon density from different observational data. Constraints from Cosmic Rays and Gamma Rays data show that locally (20 Mpc) the Universe is baryon-antibaryon asymmetric.

The exact baryogenesis mechanism is not known. Many baryogenesis models exist, the most popular among which are Great Unified Theories baryogenesis, Electroweak baryogenesis, Baryo-through-lepto-genesis and Affleck-Dine baryogenesis models. The second part of the thesis is dedicated to a variation of the SCF baryogenesis model (Dolgov, Kirilova, 1990), based on the Afleck and Dine baryogenesis scenario (Affleck, Dine, 1985).

The chemical composition of the baryonic content of the observed Universe is another intriguing issue of the contemporary cosmology and astrophysics. The baryon component of our Universe is predominantly Hydrogen and Helium, which were mainly produced during Big Bang Nucleosynthesis at the early hot stage of the Universe evolution. In contrast to baryogenesis, nowadays we know precisely the processes of light elements formation, namely BBN.

BBN is used as the most precise test of beyond the Standard model (SM) physics. Neutrino oscillations represent beyond SM physics. Present data coming from Cosmic Microwave Background and Large Scale Structures and BBN allow the existence of one light sterile neutrino, additional to the well known three active neutrino species.

Nowadays there is experimental evidence for the existence of flavor neutrino oscillations. Sterile neutrino, if present, participates in neutrino oscillations and, hence, it could be produced by neutrino oscillations. Thus, it is interesting to explore the cosmological influence of sterile neutrinos and the cosmological constraints on its parameters.

Helium-4 is the most abundant in the Universe after Hydrogen and has a simple post BBN evolution and it is the most precisely calculated and measured element. Until 2010 it was believed that the He-4 abundance is measured with 3% uncertainty, while theoretical uncertainty is less than 0.1% within a wide range of values of baryon to photon ratio. However, later it was found that the systematic errors had been underestimated and currently we know that there is a room for over 5% deviation from the mean value of the measured primordial He-4 abundance and the central value is larger than the one obtained before. We used this new observations as a base of our study of BBN with oscillations and obtained bounds on oscillation parameters for 5% He-4 overproduction.

BBN bounds on neutrino oscillation parameters

We have studied processes effecting Big Bang Nucleosynthesis during which the chemical content of the baryonic component of the Universe was produced. We have provided detail numerical analysis of production of ^{4}He, Y_p, in modified BBN model (Kirilova, Chizhov, 1997) with the presence of $\nu_e \leftrightarrow \nu_s$ neutrino oscillations, effective after electron neutrino decoupling.

We have accounted for all known effects of neutrino oscillations on cosmological nucleosyntesis: change of the expansion rate of the Universe due to the introduction of additional sterile neutrino by active-sterile oscillations, depletion of the active neutrino number density and distortion of the neutrino energy distribution and change of the neutrino-antineutrino asymmetry due to neutrino oscillations.

We have studied the role of non empty ν_s state, $\delta N_s \neq 0$, obtaining numerically ^{4}He production in the model of BBN with $\nu_e \leftrightarrow \nu_s$ neutrino oscillations for $\delta N_s = 0; 0.5; 0.7; 0.9$. We have calculated iso-helium contours for $\delta Y_p/Y_p = 5.2\%$ for $\delta N_s = 0; 0.5; 0.7; 0.9$, both for resonant and non-resonant oscillations.

Following the current available observational data for ^{4}He abundance, we have obtained cosmological bounds on oscillation parameters with initially empty sterile state $\delta N_s = 0$ and with initially partially filled sterile state $\delta N_s = 0.5; 0.7; 0.9$, corresponding to $\delta Y_p/Y_p = 5.2\%$. Analytical fits to the exact constraints for $\delta N_s = 0$ and $\delta Y_p/Y_p = 5.2\%$ have been calculated.

The main results have been obtained in refs. (Kirilova, Panayotova, 2004), (Kirilova, Panayotova, 2004a), (Kirilova, Panayotova, 2006a).

Scalar field condensate baryogenesis scenario

We have studied the processes effecting the formation of the baryon content of the Universe. We have explored a Scalar field condensate baryogenesis model consistent with inflation. We have developed a numerical procedure for accounting of the particle creation processes of damping scalar field $\varphi(t)$ and for studying the dependence of the evolution of $\varphi(t)$ and B(t) on the model parameters. Also, we have examined the role of the particle creation processes on the evolution of $\varphi(t)$ and B(t). We have shown that there is a considerable difference in the obtained results compared to the analytical approach for Γ calculation - 2 orders of magnitude (Panayotova, 2011).

The dependence of the field and baryon charge evolution and their final values on the model's parameters α, H, m, λ_i have been numerically obtained. The results could be used for construction of baryogenesis models.

We have studied the available data from Cosmic rays for $\bar{p}$, $\bar{D}$, $^4\bar{He}$ from BESS, CAPRICE, MASS, PAMELA, AMS-01, AMS-02 experiments in order to examine the possibility of existence of the significant antimatter regions in the Universe, as well. All the work concerning these problems has been described in refs. (Kirilova, Panayotova, 2006), (Kirilova, Panayotova, 2007), (Kirilova, Panayotova, 2012), (Kirilova, Panayotova, 2013).

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