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Baryon Asymmetry of the Universe Generated by Scalar Field Condensate Baryogenesis Model in Different Inflationary Scenarios

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Abstract

We analyze the baryon asymmetry value obtained for 70 sets of parameters of the Scalar Field Condensate model in different inflationary scenarios and for different reheating scenarios. We have found sets of SFC model's parameters for which the observed value of the baryon asymmetry of the Universe can be successfully generated in the following inflationary scenarios: modified Starobinsky inflation, quintessential inflation, chaotic inflation in SUGRA and chaotic inflation with delayed thermalization.

The Baryogenesis Model

We calculate the baryon asymmetry generated in the Scalar Field Condensate (SCF) baryogenesis model in different inflationary scenarios. We discuss the baryogenesis in a scalar field condensate baryogenesis model, first studied in [Dolgov, Kirilova 1990, 1991]. In this model, a complex scalar field φ, carrying baryon charge exists. During inflation a condensate <φ>≠0 with a nonzero baryon charge B is formed as a result of the rise of quantum fluctuations of φ.
B is not conserved at large field amplitude due to the presence of the B non-conserving self-interaction terms in the potential V(φ).

The equation of motion of φ is:

$$\ddot{\varphi} - a^{-2}\partial_i^2\varphi + 3H\dot{\varphi} + \frac{1}{4}\Gamma\dot{\varphi} + U'_{\varphi} = 0,$$

where a(t) is the scale factor, H=a/a and Γ is the rate of particle creation.
We choose the form of the potential as follows:

$$U(\varphi) = m^2\varphi^2 + \frac{\lambda_1}{2}|\varphi|^4 + \frac{\lambda_2}{4}(\varphi^4 + \varphi^{*4}) + \frac{\lambda_3}{4}|\varphi|^2(\varphi^2 + \varphi^{*2})$$

We assume $m \ll H_I$, λ_i of the order of the gauge coupling constant α and m is $10^2 \div 10^4$ GeV.
Since the energy density of φ at the inflationary stage is of the order H_I^4, then

$$\varphi_o^{max} \sim H_I\lambda^{-1/4} \text{and} \quad \dot{\varphi}_o = (H_I)^2$$

After inflation φ oscillates around its equilibrium point and its amplitude decreases due to the Universe expansion and the particle creation due to the coupling of the scalar field to fermions $g\varphi f_1 f_2$, where $g^2/4\pi = \alpha_{SUSY}$. Hence, the baryon charge B, contained in φ condensate, is reduced due to particle production at the high energy stage, where BV is considerable.
At low φ baryon violation becomes negligible. If Γ is a decreasing function of time the damping process may be slow enough for B to survive until t_B, when B is transferred to fermions.

The produced baryon asymmetry depends on this baryon excess B, the reheating temperature of the Universe and the value of the Hubble parameter at the inflationary stage. Namely:

$$\beta \sim N_B/T_R^3 \sim B/[H_I t_\psi]^{1/2} = BT_R/H_I$$

There are still different models of inflation discussed in literature [Linde,1990]. Reheating took place at the end of the inflationary stage and provided the transfer of the energy stored in the inflaton to other fields and enabled the beginning of the radiation dominated stage of our universe. It might have proceeded through different mechanisms (perturbative, nonperturbative), different decay channels and different decay rates of the inflaton and other particles, and different thermalization (instant or delayed) .

Here we consider the possibility for production of the observed baryon asymmetry $\beta = 6 \times 10^{-10}$ for different reheating models, different reheating temperatures and in different inflationary scenarios.

Baryon Asymmetry Results

TABLE 1. Successful production of the observed baryon asymmetry value β_{obs} for particular sets of SCF model parameters in different inflationary scenarious

Starobinski Inflation, Efficient Thermalization	$H_I = 10^{11}$ GeV; $T_R = 1.9 \times 10^9$ GeV	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 100$ GeV, $\beta_{obs} = 1.8\times10^{-9}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 200$ GeV, $\beta_{obs} = 3.3\times10^{-9}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 350$ GeV, $\beta_{obs} = 2.8\times10^{-9}$
	$H_I = 10^{12}$ GeV; $T_R = 6.2 \times 10^9$ GeV	$\lambda_1 = 5\times10^{-2}$, $\alpha = 3\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = -4.1\times10^{-9}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 5.0\times10^{-9}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 350$ GeV, $\beta_{obs} = 7.4\times10^{-10}$
Shafi-Vilenkin Chaotic Inflation, Delayed Thermalization	$H_I = 10^{12}$ GeV; $T_R = 4.5 \times 10^8$ GeV	$\lambda_1 = 10^{-2}$, $\alpha = 10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 9.5\times10^{-10}$	$\lambda_1 = 5\times10^{-2}$, $\alpha = 10^{-2}$ $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 4.5\times10^{-9}$	$\lambda_1 = 5\times10^{-2}$, $\alpha = 10^{-2}$ $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 500$ GeV, $\beta_{obs} = 1.2\times10^{-9}$
		$\lambda_1 = 5\times10^{-2}$, $\alpha = 3\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = -3.0\times10^{-10}$	$\lambda_1 = 5\times10^{-2}$, $\alpha = 5\times10^{-2}$ $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 3.6\times10^{-10}$	
Quintessential Inflation	$H_I = 10^{12}$ GeV; $T_R = 2 \times 10^5$ GeV	$\lambda_1 = \alpha = 10^{-3}$, $\lambda_2 = \lambda_3 = 10^{-4}$, $m = 350$ GeV, $\beta_{obs} = 4.3\times10^{-9}$	$\lambda_1 = 5\times10^{-3}$, $\alpha = 10^{-3}$ $\lambda_2 = \lambda_3 = 10^{-4}$, $m = 350$ GeV, $\beta_{obs} = -4.6\times10^{-10}$	$\lambda_1 = 10^{-2}, \alpha = 10^{-3}$ $\lambda_2 = \lambda_3 = 10^{-4}$, $m = 350$ GeV, $\beta_{obs} = 7.8\times10^{-10}$
		$\lambda_1 = 10^{-2}$, $\alpha = 10^{-3}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = -1.2\times10^{-9}$	$\lambda_1 = 10^{-2}, \alpha = 10^{-3}$ $\lambda_2 = \lambda_3 = 5\times10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 1.8\times10^{-10}$	$\lambda_1 = 3\times10^{-2}$, $\alpha = 10^{-3}$ $\lambda_2 = \lambda_3 = 10^{-4}$, $m = 350$ GeV, $\beta_{obs} = -7.0\times10^{-9}$
		$\lambda_1 = 5\times10^{-2}$, $\alpha = 10^{-3}$, $\lambda_2 = \lambda_3 = 10^{-4}$, $m = 350$ GeV, $\beta_{obs} = -1.1\times10^{-9}$		
Chaotic Inflation in SUGRA	$H_I = 10^{11}$ GeV; $T_R = 10^9$ GeV	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 100$ GeV, $\beta_{obs} = 9.3\times10^{-10}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 200$ GeV, $\beta_{obs} = 1.7\times10^{-9}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 350$ GeV, $\beta_{obs} = 1.5\times10^{-9}$
	$H_I = 10^{12}$ GeV; $T_R = 10^9$ GeV	$\lambda_1 = \alpha = 10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 2.1\times10^{-9}$	$\lambda_1 = 5\times10^{-2}$, $\alpha = 10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 500$ GeV, $\beta_{obs} = 2.6\times10^{-9}$	$\lambda_1 = 5\times10^{-2}$, $\alpha = 3\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = -6.6\times10^{-10}$
		$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $m = 350$ GeV, $\beta_{obs} = 8.0\times10^{-10}$	$\lambda_1 = \alpha = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-2}$, $m = 350$ GeV, $\beta_{obs} = 1.2\times10^{-10}$	

The table presents chosen parameter sets of the SFC baryogenesis model for which the value of baryon asymmetry close to the observed one is produced.

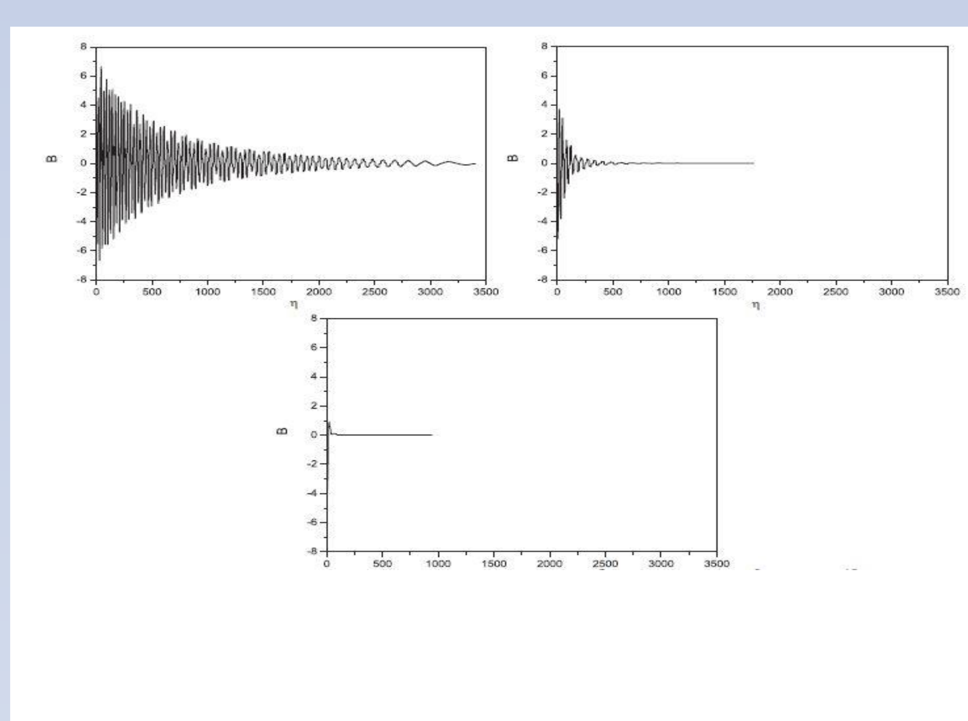

Fig.1 - The evolution of the baryon charge B(η) for $\lambda_1 = 5\times10^{-2}$, $\lambda_2 = \lambda_3 = 10^{-3}$, $H = 10^{10}$ GeV , m = 350 GeV , $\varphi_o = H_I\lambda^{-1/4}$ and $\dot{\varphi}_o = H_I^2$. The upper left plot is for $\alpha = 10^{-3}$, the upper right plot is for $\alpha = 10^{-2}$, the bottom plot is for $\alpha = 5\times10^{-2}$. The particle creation processes are accounted for numerically.

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Baryon Asymmetry in Different Inflationary Models

We calculated the baryon asymmetry value obtained for reheating temperatures T_R in different inflationary scenarios. Namely, we considered B values in the whole range of 70 parameter sets of the SFC baryogenesis model and estimated the baryon asymmetry obtained for T_R of the new inflation [Linde 1982; Albrecht, Steinhardt, 1982], chaotic inflation [Linde, 1985, 1990], Starobinsky inflation [Kofman,Linde,Starobinski, 1985], etc.

In case of *new inflation* [Dolgov A, Linde 1982; Abbot et al. 1982] $H_I=10^{10}$ GeV, $T_R=10^{14}$ GeV baryon asymmetry for all sets of model's parameters is orders of magnitudes bigger than the observed β_{obs}.

In the successful *new inflation model by Shafi and Vilenkin* [Shafi, Vilenkin, 1984] $H_I=3.10^9$ GeV, $T_R=3.10^7$ GeV, the baryon asymmetry again is much bigger than β_{obs}. $\beta > 10^{-7}$
In case of *chaotic inflation*, $H_I=10^{11}$- 10^{12} GeV, $T_R<3.10^{14}$ GeV, $\beta > 10^{-5}$

For the simplest *Shafi-Vilenkin model in chaotic inflation* $T_R=10^{12}$ -10^{13} GeV again $\beta > 10^{-7}$. However, in case of delayed thermalization T_R may be much lower, thus allowing successful baryogenesis in these chaotic inflationary models.

In case of *modified Starobinsky inflation* $T_R=0.1(\Gamma M_{Pl})^{1/2}= 10^9$ GeV, $H_I=10^{11}$GeV, successful baryogenesis is possible for the efficient thermalization as well, namely $\beta=\beta_{obs}$. $=6.10^{-10}$ was found possible for several sets of model's parameters.

For *chaotic inflation in SUGRA* [Nanopoulos, Olive, Srednicki, 1983] $T_R>10^9$GeV it is possible to generate β_{obs}.

In *MSSM inflation model* [Allahverdi et al.,2006; Ferrantelli, 2017] with H_I=1 GeV, $T_R=2.10^8$ GeV SCF baryogenesis model does not work. This inflationary model also has severe problems with gravitino overproduction, violating BBN and observed DM abundance.

In *quintessential inflation* there exist several realizations of the SFC baryogenesis model with successful production of the obsereved baryon asymmetry value, as seen from the table.

It is interesting that the inflationary models that provide successful SCB baryogenesis are also among the observationally preferred by the latest Planck data.

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