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The evolution of fields in the process of preheating in the early Universe

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Abstract. The long-term evolution of fields on the stage of primary heating of the Universe after inflation is investigated. Preheating is the stage of evolution of the Universe at which the inflaton, after the stage of slow rolling down on inflation, begins to oscillate near the minimum of its potential energy and act as a compelling external force in the equations of motion of other fields that were in a quantum state with a relatively small amplitude on inflation. Numerical calculations of the system's dynamics for long times shows that during the early phase of preheating, the energy of the material field is due to parametric resonance it grows to the energy of the inflaton. However, after a considerable duration, when the energies of the fields become aligned and there is a multiple transfer of energy from one field to another, the energy of the material field decreases faster than the energy of the inflaton. This could suggest that parametric resonance may not be sufficient for the disintegration of the inflaton and pumping its energy into the energy of material fields.

Keywords: cosmology: dark energy, early universe, inflation

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1 Introduction

At the moment, there are several ways to explain the presence of dark energy in cosmological models:

1. the cosmological constant Λ (Linde 2005);
2. vacuum energy is the vacuum condensate remaining after a series of phase transitions in the universe, but this value, calculated according to the laws of microphysics, turns out to be 120 orders of magnitude greater than the value following from astrophysical observations (Arkhipova & Pilipenko 2016);
3. an unknown evolving scalar field — quintessence — a scalar field different from the inflaton, the density of which was very small, but over time, due to evolution, it began to dominate (Arkhipova & Pilipenko 2016; Avsadzhanishvili et al. 2014);
4. gravity modified over long distances (Rubakov & Tinyakov 2008);
5. the relic of inflation is an undeveloped part of the inflaton field.

In this paper, we will focus on the last point.

The theory of cosmological inflation, which leads to the exponential evolution of the scale factor, thanks to a certain scalar inflaton field, has solved many problems existing in cosmology (Linde 2005). These includes the flatness problem, the isotropy and uniformity of space and time, independence from the initial conditions, the sufficient growth of primary inhomogeneities, and the isotropy of cosmic background radiation anisotropy.

According to modern concepts, inflation occurred in the time interval from 10^{-42} s to 10^{-36} s. The condition of inflation is the condition of slow rolling, i.e. the excess of the potential energy of the field over the kinetic one, during this process the potential energy of the field decreases. At the end of inflation, the inflaton begins to oscillate near the minimum of its potential energy. And this moment, the history of the hot universe begins, as inflaton energy is pumped into material fields that are inflated in a quantum state. Particles are formed, thermalize, and the concept of temperature appears, which is quite high at this moment.

A "parametric resonance" is proposed as a possible explanation of the mechanism of this stage. There are various methods to establish the type of inflaton potential and material fields, along with the nature of their interactions, leading to a diverse range of models. The specific type of potential and interaction, as well as the method of setting initial values, is determined by the selected theory.

2 Inflation and preheating model

In this paper, we solve the problem of the numerical modeling of postinflationary heating using Lagrangian fields in the early Universe of the form $L = L_\phi + L_\chi$, consisting of a part belonging to the inflaton ϕ and some scalar field χ, which was at the stage of inflation in a quantum state with a very small amplitude, where

$$L_\phi = \frac{1}{2}\phi_{;i}\phi^{;i} - V(\phi), \tag{1}$$

$$L_\chi = \frac{1}{2}\chi_{;i}\chi^{;i} - g^2\phi^2\chi^2, \tag{2}$$

and $g^2(\phi)^2\chi^2$ is responsible for the interaction of fields.

In this article, the potential of the ϕ field is considered as follows eq. (3):

$$V(\phi) = \frac{1}{2}m^2\phi^2. \tag{3}$$

By varying the Lagrangians eq. (1)–(2) over the fields, we derive a system of equations that describes all stages of the system's evolution:

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0, \tag{4}$$

$$\ddot{\chi} + 3H\dot{\chi} + V_{,\chi} = 0, \tag{5}$$

$$H^2 = \frac{\ddot{a}}{a} = \frac{8\pi G}{3}(\frac{\ddot{\phi}^2}{2} + \frac{\ddot{\chi}^2}{2} + V(\phi) + V(\chi)), \tag{6}$$

where H — is the Hubble parameter.

The numerical solution of this system (3)–(6) for the evolution of field energy is shown in Fig.1.

3 Results and conclusions

Numerical calculations of the system's dynamics for a long time shows that immediately after inflation, during initial phase of preheating, the energy of the material field increases due to parametric resonance to the energy of the inflaton, and its energy is pumped into the energy of the material fields. And after quite a considerable time, the energies of the fields become aligned, and energy is pumped from one field to another and back. Then the energy of the material field decreases faster than the energy of the inflaton.

In this model, with a given fixed constant of interaction between the inflaton and the material field, the mechanism of parametric resonance does not result in the complete disintegration of the inflaton and pumping of its energy into the energy of

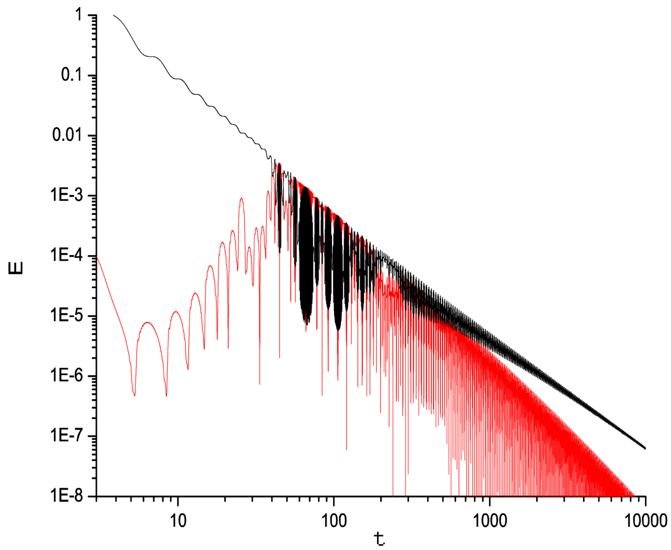

Fig. 1. The evolution of field energy in the model, $g = 100$. The black curve shows the evolution of the inflaton, and the red one shows the evolution of the energy of the material field. Time is measured in conventional units.

the material field. Moreover, the remaining energy of the inflaton tends to dominate over time, which can be interpreted as a manifestation of dark energy contributing to the repeated accelerated expansion of the Universe (Riess et al. 1998; Perlmutter et al. 1999).

In the future, there are plans to explore the impact of the interaction constant value and various types of inflaton potentials on the process of preheating.

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