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ELEMENTARY PARTICLES AND FIELDS
Theory

Local Heating of Matter in the Early Universe owing to the Interaction of the Higgs Field with a Scalar Field

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Abstract—It is shown that the formation of primordial massive black holes may be accompanied by a local heating of matter. The proposed heating mechanism is based on the interaction of the Higgs field with a scalar field that is responsible for the formation of black holes.

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1. INTRODUCTION

The most recent investigations [1–5] revealed that the formation of quasars characterized by a redshift value in excess of six ($z > 6$) does not fit in standard models intended for describing the creation of galaxies and stars. At the same time, there are models that predict the existence of primordial black holes (PBH) [6–9] in the early Universe; in turn, these black holes may lead to the formation of quasars.

In the present study, we consider a new mechanisms of plasma heating around primordial black holes formed upon the collapse of domain walls [8]. The proposed heating mechanism is based on the interaction of a classical Higgs field with a scalar field that is responsible for the formation of a primordial black hole. Such an interaction may arise owing to quantum corrections.

The Lagrangian of the model used here has the form

$$L = (\partial_\mu h)^\dagger(\partial_\mu h) - V_h(|h|) + (\partial_\mu\phi)^2 - V_\phi(\phi) + L_{\rm int}, \quad (1)$$

where h and ϕ are, respectively, the Higgs field and the aforementioned scalar field;

$$V_h(|h|) = \lambda(h^\dagger h)^2 - \mu^2 h^\dagger h = \lambda(h^\dagger h - v_{\rm H}^2)^2 \quad (2)$$

is the standard Higgs potential whose vacuum expectation value is $v_{\rm int} = \frac{\mu}{\sqrt{2\lambda}}$; and $V_\phi(\phi)$ and $L_{\rm int}$ are, respectively, the potential of the field ϕ and the term that describes the interaction of the fields ϕ and h. The last two quantities were chosen as

$$V_\phi(\phi) = \lambda_\phi\phi^2(\phi - v_\phi)^2 \quad (3)$$

and

$$L_{\rm int} = g(h^\dagger h)\phi^2. \quad (4)$$

It is assumed that, in the postinflation epoch, the space in the Universe is filled with a true scalar-field vacuum, where $\phi = 0$, and spurious-vacuum domains, where $\phi = v_\phi$, are also contained in it. Because of the term given by Eq. (4), the vacuum expectation value of the Higgs field within such domains has a different value. As a result, particle masses within a domain will be different from their counterparts outside it. As soon as a domain wall undergoes a collapse leading to the formation of a primordial black hole, there occurs the deposition of the energy corresponding to the difference of masses in the regions where $v_{\rm H}$ has different values. Below, we examine this mechanism in more detail.

2. LOCAL PLASMA HEATING IN THE EARLY UNIVERSE

Let us consider the space within a domain where the vacuum mean field has the value $\phi = v_\phi$ (spurious vacuum). The contribution of the term $gv_\phi^2(h^\dagger h)$ to the potential of the Higgs field has the form

$$V(|h|) = \lambda(h^\dagger h)^2 - (\mu^2 + gv_\phi^2)h^\dagger h = \lambda(h^\dagger h - (v_{\rm H}^{\rm new})^2), \quad (5)$$

where

$$(v_{\rm H}^{\rm new})^2 = v_{\rm H}^2 + \frac{g}{2\lambda}v_\phi^2 \quad (6)$$

is the new vacuum expectation value of the Higgs field. The fermion mass changes to become

$$m_i^{\rm new} = g_i v_{\rm H}^{\rm new}, \quad (7)$$

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