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INFLATIONARY EXPANDING UNIVERSE BY A COMPOSITE SCALAR FIELD

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ABSTRACT

A composite scalar field has been investigated as an alternative candidate for the inflaton field. The gauged Nambu-Jona-Lasinio model is employed as an simple model of the composite scalar field. The model can be described by the gauge-Higgs-Yukawa theory with the corresponding compositeness conditions. We conclude that the inflation induced by a composite scalar field predicts consistent CMB fluctuations.

Keywords: *Nambu-Jona-Lasinio model, gauge-Higgs-Yukawa theory, composite scalar field*

One of the basic concepts of the particle physics is symmetry and its breaking. It is considered that a more fundamental theory with a higher symmetry realizes and the symmetry is broken down at high energy scale. Hence, there is possibility to test the fundamental model by observing the critical phenomena induced by symmetry breaking at early universe.

A simple model of the symmetry breaking has been introduced by Y. Nambu and G. Jona-Lasinio to study the meson physics, low energy phenomena of QCD [1]. A scale up version of the model has been applied at the electroweak symmetry breaking is known as Technicolor model (see, for example [2]). Here we regard the gauged Nambu-Jona-Lasinio (NJL) model as a simple prototype model at inflationary expanding era of our universe and investigate the evolution of the universe.

We start from the $SU(N_c)$ gauged NJL model with N_f-flavor fermions,

$$L_{qNJL} = L_{qauqe} + \overline{\psi} i\hat{D}\psi + \frac{16\pi^2 q_4}{8N_f N_c \Lambda^2}\left[(\overline{\psi}\psi)^2 + (\overline{\psi} i\gamma_5 \tau^a \psi)^2 \right], \tag{1}$$

where L_{qauqe} denotes the pure $SU(N_c)$ gauge Lagrangian and τ^a indicates the generator of $SU(N_f)$ flavor symmetry. We normalized the four-fermion coupling, g_4 by N_f, N_c and the compositeness scale, Λ. The Lagrangian can be rewritten by the auxiliary field method,

$$L_{aux} = L_{qauqe} + \overline{\psi}\left(i\hat{D} - \sigma - \tau^a \pi^a \right)\psi - \frac{2N_f N_c \Lambda^2}{16\pi^2 q_4}\left(\sigma^2 + \pi^{a2} \right). \tag{2}$$

where the fields, σ and π, can be identified with composite scalar and pseudo-scalar fields, respectively. On the other hand, the gauged Higgs Yukawa theory is given by

$$L_{qHY} = L_{qauqe} + \frac{1}{2y^2}\partial_\mu \sigma \partial^\mu \sigma + \frac{1}{2y^2}\partial_\mu \pi^a \partial^\mu \pi^a - \frac{1m^2}{2y^2}\left(\sigma^2 + \pi^a \pi^a \right) -$$

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$$-\frac{\lambda}{4y^4}\left(\sigma^2+\pi^a\pi^a\right)^2-\frac{1\xi}{2y^2}R\left(\sigma^2+\pi^a\pi^a\right)+\bar{\psi}i\hat{D}\psi-\bar{\psi}\left(\sigma+i\gamma_5\tau^a\pi^a\right)\psi, \tag{3}$$

where y indicates the Yukawa coupling. We noted that the ordinary gauged Higgs Yukawa Lagrangian is obtained by the replacements, $\sigma \to y\sigma$ and $\pi^a \to y\pi^a$.

The compositeness conditions are imposed at the scale Λ [3, 4],

$$\frac{1}{y^2(\Lambda)}=0,\quad \frac{\lambda(\Lambda)}{y^4(\Lambda)}=0,\quad \frac{m^2(\Lambda)}{y^2(\Lambda)}=\frac{2N_fN_c\Lambda^2}{16\pi^2 g_4},\quad \xi(\Lambda)=\frac{1}{6}. \tag{4}$$

Eqs. (2) and (3) coincide under these conditions. Evaluating the renormalization group equation with neglecting the running of the $SU(N_c)$ gauge coupling and the higher order terms in the curvature, *R*, we obtain the solution to satisfy these conditions [5, 6]. Therefore we regards the gauged Higgs Yukawa theory with the compositeness conditions as an effective theory of the gauged NJL model below the compositeness scale, *Λ*.

As is illustrated in Fig. 1, we assume that the dominant contribution to the energy density of the universe can be described by the gauged Higgs Yukawa theory with the compositeness conditions at the inflationary expanding era. We also assume that only the field, σ, con-

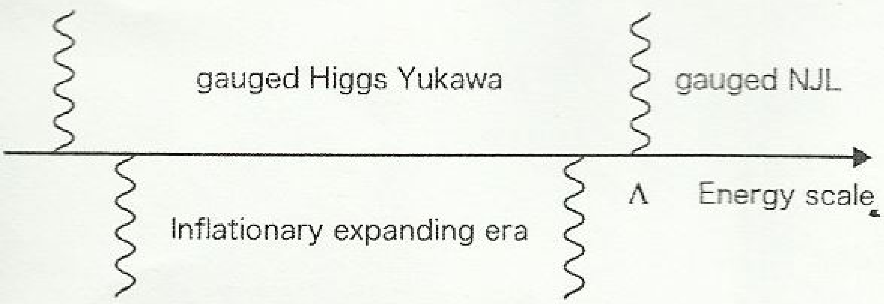

Figure 1: Assumed energy scale

tributes the inflationary expansion and apply the slow roll scenario of the chaotic inflation.

Starting from the renormalization group improved effective potential for the gauged Higgs Yukawa theory with the compositeness conditions, we evaluate the inflationary parameters [7]. Our model has parameters, the gauge coupling, *α,* the four-fermion coupling, g_4, the number of fermion spices, N_c and N_f, the energy scale, μ and the composite scale, *Λ*. The initial field configuration is set to generate an enough e-folding number, N_{efold} = 50 ~ 60.

After some numerical calculations we obtain the amplitude of the density fluctuation, δ, the spectral index, n_s, the tensor-to-scalar-ratio, r and the running of the spectral index, α_s. In Tab. 1 we show some typical results for a fixed N_f, N_c, μ *Λ* and N_{efold}. *A* constant

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Table 1: Inflationary parameters for $N_f = 1$, $N_c = 10$, $\mu = 10^{-5}M_{pl}$, $\Lambda = M_{pl}$ and $N_{efold} = 50$.

α	$1/g_{4ren} - 1/\omega$	δ	n_s	r	α_s
10^{-7}	10^{-1}	7.02×10^{-4}	0.970	0.08	-0.00059
10^{-8}	10^{-1}	2.22×10^{-4}	0.970	0.08	-0.00059
10^{-9}	10^{-1}	7.02×10^{-5}	0.970	0.08	-0.00059
10^{-9}	10^{-3}	7.02×10^{-6}	0.970	0.08	-0.00059
10^{-9}	10^{-5}	7.48×10^{-7}	0.968	0.11	-0.00061

parameter, ω, is introduced to define the renormalized four-fermion coupling, g_{4ren}. The amplitude of the density fluctuation, δ, can be tuned by strength of the interactions, α, and g_{4ren}. The other parameter dependence is much smaller. We also found that the spectral index, the tensor-to-scalar-ratio and the running of the spectral index are consistent with the Planck 2015 data.

A composite scalar field has been investigated as an alternative candidate for the inflaton field. The gauged Nambu-Jona-Lasinio model is employed as an simple model of the composite scalar field. The model can be described by the gauge-Higgs-Yukawa theory with the corresponding compositeness conditions. Evaluating the renormalization group improved effective potential, we have calculated the inflationary parameters: the amplitude of the density fluctuation, the spectral index, the tensor-to-scalar-ratio and the running of the spectral index. Under the slow roll approximation and some assumptions it is shown that the model predicts consistent the spectral index, the tensor-to-scalar-ratio and the running of the spectral index. Therefore we conclude that the inflation induced by a composite scalar field predicts consistent CMB fluctuations.

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