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# Plasma-Driven Inflation

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The possibility of inflation without any genuine scalar is discussed. It is suggested that drops of primordial plasma may drive inflation. The model, although naive, is consistent with observational data.

## 1. INTRODUCTION

Inflation seems to be the only way of evolution of a hot universe that can lead to the observed space-time structure (Linde, 1989; Domingues-Tenreiro and Quiros, 1988; Kämper *et al.*, 1989). In its new version, inflation is driven by a scalar field with the following potential (Linde, 1982; Albrecht and Steinhard, 1982):

$$V_{\text{eff}}=B\phi^4\left(\ln\frac{\phi^2}{\sigma^2}-\frac{1}{2}\right)+\frac{1}{2}B\sigma^4+C\phi^2 \tag{1}$$

The equation of motion of the scalar field takes the form

$$[g_{\mu\nu}=\text{diag}(1, -R^2(t), -R^2(t), -R^2(t))]$$

$$\ddot{\phi}+3H\dot{\phi}+\frac{dV}{d\phi}-R^{-2}\Delta\phi=0 \tag{2a}$$

$$\left(\frac{\dot{R}}{R}\right)^2+\frac{k}{R^2}=\frac{1}{3}\rho \tag{2b}$$

Equation (2b) has a solution of the form $R(t)=e^{H_I t}$ for large $R(t)$, where $H_I$ is the Hubble constant during the inflationary epoch. Although potentially successful, the inflationary scenario has several drawbacks. First, it requires

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the existence of scalar fields. Presently we have no experimental evidence that scalar fields are realized in the universe we live in. Unified theories provide us with scalar Higgs fields, but even in their modest realization, the GSW model, the existence of the Higgs particle has not been confirmed. The superstring-inspired models (Green *et al.*, 1986; Sładkowski, 1990*a*) predict the existence of various kinds of (pseudo-) scalar fields. Nevertheless, though very important, the notion of scalar particle has remained only a theoretical gadget. Second, what are the effects of other fields? Is the analysis of the evolution of a scalar field a realistic approximation? I would like to address the above problems. The main result is that drops of "primordial plasma" may drive inflation.

## 2. DESCRIPTION OF THE MODEL

Suppose the GUT scenario is correct. This means that shortly after the Big Bang the effects of quantum gravity can be neglected and the elementary particle interactions are described in terms of non-Abelian gauge theory. How is one to describe such a hot and strongly interacting matter? A possible answer to the problem is suggested by the non-Abelian form of the gauge interactions. Namely, the very hot matter should take the form of drops of "primordial plasma." Such drops should be chargeless with respect to the GUT gauge fields. The reason is twofold. First, the interaction range is infinite, so only white (in the QCD language) objects can be considered as separate objects. Second, the non-Abelian force between elementary objects is gauge dependent and should decouple from the "external" gauge-invariant world: drops of primordial plasma should behave as hadrons do.

How is one to describe the interaction of such a primordial soup? The answer is suggested by nuclear physics. Nuclear forces (QCD) can be effectively described by exchange of mesons. Such approximations are usually very good (cf. Fermi theory of weak interactions). If the drops are large, we can neglect their total spins and use a scalar field to describe their interaction (the possible spin effect may be reduced to a change in the form of the potential):

$$L_{\text{eff}} = g^{1/2}[\partial_\mu \phi\, \partial^\mu \phi + V_{\text{eff}}(\phi)] \tag{3}$$

When such bubbles collide, the surface tension causes the bubbles to coalesce until they reach a characteristic radius $r_b$ and for a brief period this coalescence would be the most important process, but after reaching the characteristic size $r_b$, the bubble coalescence (effectively) stops. The value of $r_b$ may be quite big (Witten, 1984). Thus, the form of the potential $V_{\text{eff}}(\phi)$ will depend on temperature. This and the exchange of white "primordial mesons" suggest the following form of the effective potential:

$$V_{\text{eff}}(\phi) = g^{1/2}[a(t)\phi^2 + b(t)\phi^3 + c(t)\phi^4 + V_0(t, T)] \tag{4}$$

The term denoted by $V_0(t, T)$ describes the possible and complicated effects of spin and so on. I will suppose that this term is small, or at least quickly vanishes as the universe expands. The functions $a(t)$, $b(t)$, and $c(t)$ will decrease with time due to the increasing separation of droplets (the interaction will eventually cease due to the separation). Thus, after some period of evolution of the universe the coefficients $a$, $b$, and $c$ would become small enough to start inflation. In the simplified version, $b=0$, the one-loop effective potential will take the form

$$\begin{aligned} V_{\text{eff}}^{(1)} = a\phi^2 + c\phi^4 + \frac{1}{(8\pi)^2}\bigg[&(12c\phi^2 + 2a)^2 \ln\left(1 + \frac{6c\phi^2}{a}\right) \\ &- 12c\phi^2(18\phi^2 + 2a)\bigg] + \cdots \end{aligned} \tag{5}$$

In this way the fine tuning problem is solved: the time evolution of the coefficients will provide us with the needed values. The cosmological constant problem is also solved in this way. The precise form of the scalar potential may actually be different from equation (4). If the grand unification gauge group has some Abelian factor $U(1)^n$, then the scalar field Lagrangian would be a modified version of scalar electrodynamics. The droplets will be charged with respect to the $U(1)$'s and the potential (4) will be modified by the gauge interaction term. Exponential terms are also possible (Ratra, 1989).

If this scenario is to be accepted, two questions must be answered. Is the description of the "primordial soup" as a scalar field realistic? What is the physical interpretation of scalar field? In general, the matter distribution influences the space-time geometry because it determines the right-hand sides of Einstein's equations. It seems to be reasonable that for large droplets spin effects are negligible. In that case the matter distribution should be governed by a sort of scalar field evolution. This is usually done in inflationary models. In "orthodox" models we require the existence of scalar fields with almost classical evolution, so that equations (2) are valid. I would like to stress that, taking a hint from strong interaction physics, in the early epoch matter may have behaved as a scalar field. If this is true, the inflationary scenario is very plausible, but it is driven by the matter as a whole, not just simply by a genuine scalar field.

## 3. CONCLUSIONS

The proposed model has the virtues of the new inflation scenario with a nearly Coleman–Weinberg potential. The problem of smallness of the coupling constant [$B$ in equation (1) should be smaller than $8 \times 10^{-5}$, but the actual value is $B = 5.49 \times 10^{-2}$] is probably absent if the approximation given by equation (4) is correct. Inflation of the proposed type is consistent with the superstring-inspired models (Green *et al.*, 1986; Sładkowski, 1990*a*,*b*), at least with those with dynamically broken gauge symmetry (Mańka and Sładkowski, 1989*a*; Sładkowski and Mańka, 1989). Small-scale inhomogeneity of the universe is explained in a natural way: clusters are caused by "decay" of single drops.

Note that the standard baryogenesis will take place. The appropriate particle would be released at different stages of gauge symmetry breaking. At present, only hadrons form such "drops" because the $SU(3)_c$ is still unbroken.

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