SOME CRITICAL REMARKS ON THE INFLATIONARY UNIVERSE CONCEPT

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The basic idea of inflation in cosmology is very simple: It is the assumption that the expansion factor R(t) of a Friedmann-Lemaitre cosmological model grows exponentially during a brief time interval in the very early universe. The phase of exponential growth is followed by a thermalization stage and a subsequent "normal" evolution $R(t) \sim \sqrt{t}$. This "inflationary expansion" can help to solve cosmological puzzles inherent in the standard model – such as the large-scale flatness, the horizon structure, the numerical value of the entropy in a comoving volume [for a review see Brandenberger 1985]. To turn this romantic idea of inflation into a quantitative model requires still a lot of work: The simple change in the thermal history of the universe must be derived from a fundamental particle theory. The models proposed so far do not inspire much confidence. In the following a few difficulties of the Higgs field idea, especially the Coleman-Weinberg formalism will be pointed out (section 1). In section 2 some problems connected with the investigation of initially strongly anisotropic or inhomogeneous cosmological models will be mentioned.

1. Problems in the Particle Physics Input

There is no generally accepted model for a unified theory of elementary particles, but quite generally the concept of a large local gauge symmetry G is usually supplemented in grand unified theories (GUT) by the introduction of selfinteracting scalar fields which serve to give a mass to some of the gauge bosons. The self-interaction of the Higgs field ϕ

$$V(|\phi|) = \lambda|\phi|^4 - \sigma|\phi|^2 \qquad (\lambda > 0) \tag{1}$$

has a maximum (depending on the parameters) at $|\overset{o}{\phi}|^2 = \sigma/2\lambda$ (Higgs phase), with $V''(|\phi|) > 0$. Usually a representative state from the

J. Audouze et al. (eds.), Large Scale Structures of the Universe, 63–65.

ground state orbit is chosen to define the ground state in the symmetric ($|\phi| = 0$) and the Higgs phase ($|\phi| = \sqrt{\sigma/2\lambda}$).

A semiclassical picture is often employed which assumes spontaneous symmetry breaking, i.e. a nonzero expectation value $\langle\phi(x)\rangle \neq 0$ in the Higgs phase. Inflationary models use this idea to describe a phase transition of the universe field with Higgs fields with the expectation value $\langle\phi(x)\rangle$ acting as an order parameter. The classical potential energy $V(|\phi_c|)$ then has a nonzero "vacuum energy density" $|V(0)-V(\sigma/2\lambda)|$ which can appear like a constant energy density in the Friedmann equation. Inflation occurs when this constant energy density becomes dominant.

This semiclassical picture may be a reasonable description in lowest order perturbation theory, but to test its reliability it should be contrasted to the exact results from model theories.

Studies of Abelian Higgs models on a lattice have yielded mixed results:

i) Without fixing the gauge there is no spontaneous symmetry breaking, i.e. $\langle\phi(x)\rangle = 0$ everywhere [see e.g. Borgs, Nill 1986].

ii) The gauge can be fixed by requiring the gauge transformations to be unity in a fixed direction (axial gauge) [Fröhlich, Morchio, Strocchi 1981] then also $\langle\phi\rangle = 0$.

iii) The so-called α-gauges consist in adding a term $1/2\alpha\, \Sigma\, (\partial_\mu A_\mu)^2$ to the (euclidean) action. Then for $\alpha \simeq 0$ there is no spontaneous symmetry breaking, $\langle\phi\rangle = 0$, in dimensions $d \leq 4$. The reasons ly in spinwave contributions $\sim d^dk/(k^2)^2$ at $k \approx 0$ [Kennedy, King 1985; Borgs, Nill 1986]

iv) For $\alpha > 0$, $G = U(1)$, and the coupling $g^2 >> 1$, again $\langle\phi\rangle = 0$.

The exception is the noncompact case $G = \mathbb{R}$ ($\sigma << -1$, $g^2 << 1$, $\lambda << 1$), where indeed $\langle\phi\rangle \neq 0$ [cf. Nill 1987; Borgs, Nill 1986; Kennedy, King 1985].

The semi-classical picture looses 1:3, but perhaps it wins in cosmology.

In a perturbation approach to quantum field theory the effective potential $V_{eff}(|\phi|)$ – interpreted as the thermodynamic Helmholtz free energy for the fields ϕ – is computed in "loop" approximations which are basically an expansion in orders of $\hbar$, of the Euclidean action $S_E/\hbar$. The "1-loop" approximation of the Coleman-Weinberg type gives a double-hump potential with a relative maximum at $|\phi_c| = 0$. This is used in inflationary models to describe the time-evolution of the classical scalar field ϕ_c, according to

$$\Box_g\ \phi_c = V'_{eff}(\phi_c). \qquad (2)$$

The effective potential V_{eff} must, however, be strictly convex, and the 1-loop expansion can therefore not be used to describe a time evolution of the scalar field [e.g. Börner, Seiler 1984].

These criticisms apply only to specific versions of the inflationary model, but it remains to be seen whether other suggestions, such as "chaotic inflation" [Linde 1985], can survive a more precise scruting.

2. Problems with the Input from General Relativity

Most models start already in a homogeneous and isotropic FL universe at $t < 10^{-35}$ sec. But the inflationary concept is of value only, if it works in more general initial conditions. A few more general cases have been investigated.

i) It is found that in anisotropic and homogenous models the anisotropy is strongly reduced by an inflationary phase (Rothman & Ellis 1986). Inhomogeneous and anisotropic cosmologies give rise to a stable state $<\phi> = 0$ if the initial anisotropy is too large, only for reasonably small values does the universe recenter a FL-like stage (Barrow & Turner 1982; Börner & Götz 1987).

ii) There are many choices in deSitter space for a time direction. How then can the choice of a spatially homogeneous time direction be guaranteed during the transition from a vacuum-energy dominated deSitter space to a radiation-dominated FL universe?

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