International Journal of Theoretical Physics, Vol. 31, No. 7, 1992

Nonstandard Model of the Expanding Universe

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Received August 18, 1991

A reformulation of general relativity is proposed with the relativity principle being invalid. Consequently the space-time manifold carries a natural (1 + 3)-foliation, where the foliation variables supersede the metric as the fundamental object. The Einstein equations become modified by some kind of foliation energy, but otherwise remain part of the dynamics. The theory is applied to a homogeneous and isotropic universe; the generation of mass can be explained by conversion of foliation energy and inflation is driven by the negative foliation pressure.

1. INTRODUCTION

The notorious deficiencies of the standard cosmological model (i.e., horizon, flatness, smoothness, and singularity problems) have been given a very elegant solution through the notion of cosmic inflation (Turner, 1987; Blau and Guth, 1987; Linde, 1987). However, since this idea is still based upon the validity of the traditional Einstein equations, one has to introduce some physical system which is capable of developing negative pressure on a cosmic scale in order to blow up the universe. Such a peculiar system has been proposed as a weakly coupled scalar field subject to the well-known Higgs mechanism. Indeed, whenever the scalar field is in the "false vacuum," its energy-momentum content may be described by a "cosmological term" which is known to be responsible for cosmic inflation. Moreover, the energy released through the transition into the "right vacuum" is considered as the origin of the matter in the universe ("creation *ex nihilo*").

An appropriate scalar field of the desired kind seems to be provided by (at least some of) the grand unified theories, so that presently much attention is being given to those inflationary scenarios. However, it would seem desirable to have more than one single mechanism supporting the phenomenon

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0020-7748/92/0700-1229$06.50/0

of inflation. Even if the GUTs should turn out to be not viable, inflation will nevertheless continue to be a very attractive explanation for the observed evolution of the universe. Therefore an alternative foundation of the idea of inflation would be highly welcome.

We shall present such an alternative by modifying somewhat the traditional theory of relativity. This yields a potential competitor to the Higgs mechanism for curing some of the deficiencies of the standard model; in the present paper we restrict ourselves to a brief summary of the basic ideas together with a short demonstration of inflationary solutions. The essential point here is that it is gravitation itself which is able to produce the desired negative pressure, so that no extra physical system has to be introduced. The only thing that has to be added to the conventional Einstein theory is the assumption that the space-time manifold carries a natural foliation, where the foliation variables are to be considered as dynamical objects contributing to the energy-momentum content of the universe.

2. FOLIATION DYNAMICS

The starting point consists in the somewhat heretic postulate that the relativity principle is not valid on a *cosmic* scale, albeit it may be a good approximation for *local* physics. Consequently, the space-time manifold will carry a natural $(1+3)$-foliation to be considered as the basic dynamical object of the theory in place of the metric $\mathbf{G}$, which itself may be constructed afterward from the foliation variables. As the latter, we chose a tetrad field $\{\mathbf{e}_\mu\} = \{\mathbf{p}; \mathscr{B}_i\}$, such that the three vectors $\mathscr{B}_i$ ($\equiv \mathbf{e}_i$; $i = 1, 2, 3$) define a 3-distribution $\overset{\frown}{\Delta}$ and the remaining "characteristic vector" $\mathbf{p}$ ($\equiv \mathbf{e}_0$) defines the complementary 1-distribution $\overset{\smile}{\Delta}$ of the $(1+3)$-foliation. Both distributions are made orthogonal by defining the metric $\mathbf{G}$ as

$$G_{\mu\nu} = \mathscr{B}^i{}_\mu \mathscr{B}_{i\nu} + p_\mu p_\nu \tag{2.1}$$

This metric automatically orthonormalizes the tetrad vectors; additionally, it becomes covariantly constant

$$\nabla_\lambda G_{\mu\nu} = 0 \tag{2.2}$$

when the "foliation dynamics" is selected as

$$\nabla_\mu p_\nu = \mathscr{H}_{i\mu} \mathscr{B}^i{}_\nu \tag{2.3a}$$

$$\bar{\mathscr{D}}_\mu \mathscr{B}_{i\nu} = -\mathscr{H}_{i\mu} p_\nu \tag{2.3b}$$

Here, the coordinate covariant derivative ∇ refers to the Levi-Civita connection Γ of the metric $\mathbf{G}$ in (2.1) and $\bar{\mathscr{D}}$ is the (gauge plus coordinate) covariant derivative due to the $\mathscr{SO}(3)$ projection $\bar{\mathbf{A}}$ of the $\mathscr{SO}(1, 3)$-valued gauge copy $\boldsymbol{\omega}$ of $\boldsymbol{\Gamma}$, i.e.,

$$\bar{\mathscr{D}}_\mu \mathscr{B}_{i\nu} = \nabla_\mu \mathscr{B}_{i\nu} + \varepsilon_i{}^{jk} \bar{A}_{j\mu} \mathscr{B}_{k\nu} \qquad (\bar{\mathbf{A}} := \boldsymbol{\omega}|_{\mathscr{SO}(3)}) \tag{2.4}$$

Obviously, there are two further dynamical objects besides the foliation variables $\{\mathbf{p}, \mathscr{B}_i\}$ entering the equation of motion (2.3a), (2.3b): these are the $\mathscr{SO}(3)$ connection $\bar{\mathbf{A}} = \{\bar{A}_{i\mu}\}$ and the "Hubble (gauge) vector" $\mathscr{H} = \{\mathscr{H}_{i\mu}\}$, which parametrize the Lorentz connection $\boldsymbol{\omega}$ through

$$\boldsymbol{\omega} = \bar{\mathbf{A}}_i L^i - \mathscr{H}_i l^i \tag{2.5}$$

where L^i (l^i) are the usual rotation (boost) generators of the local Lorentz group. Being proper dynamical objects of the theory, both variables $\bar{\mathbf{A}}$ and $\mathscr{H}$ are required to obey some equation of motion supplementing the foliation dynamics (2.3a), (2.3b).

Before specifying this dynamical law, one introduces a further $SO(3)$ gauge vector $\mathbf{C} = \{C_{i\mu}\}$ leading to a modified $\mathscr{SO}(3)$ connection $\mathbf{A}$,

$$A_{i\mu} = \bar{A}_{i\mu} - C_{i\mu} \tag{2.6}$$

and then one writes down a Yang–Mills–Higgs equation for the curvature $\mathbf{F}$ of $\mathbf{A}$:

$$\mathscr{D}^\mu F_{i\mu\nu} = \frac{1}{c^2} \varepsilon_i{}^{jk} (\mathscr{D}_\nu \mathscr{B}_{j\mu}) \mathscr{B}_k{}^\mu \qquad (c = \text{const}) \tag{2.7}$$

The motivation for such a procedure will become clear during the subsequent search for an equation of motion for the last dynamical variable $\mathscr{H}$.

The solution of this remaining dynamical problem offers itself by considering the integrability conditions for the foliation dynamics (2.3a), (2.3b). Assuming that the coefficient objects $\bar{\mathbf{A}}$, $\mathscr{H}$ are already known, one can easily show that these equations of motion admit solutions $\{\mathbf{p}(x), \mathscr{B}_i(x)\}$ only if the underlying space-time geometry has a curvature tensor $\mathbf{R}$ of the following form:

$$R^\lambda{}_{\nu\sigma\mu} = \overset{\frown}{R}{}^\lambda{}_{\nu\sigma\mu} + \overset{\smile}{R}{}^\lambda{}_{\nu\sigma\mu} \tag{2.8a}$$

$$\overset{\frown}{R}{}^\lambda{}_{\nu\sigma\mu} := \varepsilon^{ijk} \mathscr{B}_i{}^\lambda \bar{F}_{j\sigma\mu} \mathscr{B}_{k\nu} \tag{2.8b}$$

$$\overset{\smile}{R}{}^\lambda{}_{\nu\sigma\mu} := H^\lambda{}_\mu H_{\nu\sigma} - H^\lambda{}_\sigma H_{\nu\mu} + p_\nu (\nabla_\sigma H^\lambda{}_\mu - \nabla_\mu H^\lambda{}_\sigma) - p^\lambda (\nabla_\sigma H_{\nu\mu} - \nabla_\mu H_{\nu\sigma}) \tag{2.8c}$$

Here, $\bar{\mathbf{F}}$ is the curvature of the original connection $\bar{\mathbf{A}}$,

$$\bar{F}_{i\mu\nu} \equiv \partial_\mu \bar{A}_{i\nu} - \partial_\mu \bar{A}_{i\nu} + \varepsilon_i^{jk} \bar{A}_{j\mu} \bar{A}_{k\nu} \tag{2.9}$$

and **H** is the Hubble tensor associated to the vector $\mathscr{H}$ according to

$$H_{\mu\nu} := \mathscr{B}^{i}{}_{\mu} \mathscr{H}_{i\nu} \tag{2.10}$$

Now, since the first-order derivatives of $\bar{\mathbf{A}}$ and $\mathscr{H}$ enter the curvature **R** of (2.8a)–(2.8c), we obtain the desired equation of motion for these fields by postulating the Einstein field equations, reading in geometric units (Mattes and Sorg, 1989*a*)

$$E_{\mu\nu} = 8\pi L_{\mathrm{P}}^{2} T_{\mu\nu} \qquad (L_{\mathrm{P}} \text{ is the Planck length}) \tag{2.11}$$

Thus, the relevance of the Einstein equation persists in the theory as the dynamical equation for $\bar{\mathbf{A}}$ and $\mathscr{H}$, but its dominant role is weakened somewhat in favor of the foliation dynamics (2.3a), (2.3b), and (2.7). When the energy-momentum density **T** on the right-hand side of the Einstein equations (2.11) has been specified in terms of the space-time geometry, the system of equations (2.3a), (2.3b), (2.7), and (2.11) constitutes a complete and consistent dynamical theory of the foliated space-time manifold, which is considered as a viable alternative to the Einstein approach.

3. FOLIATION ENERGY

As far as the Einstein equations (2.11) are concerned, the present viewpoint mainly differs from the traditional approach with respect to the energy-momentum density **T** to be substituted on the right: assuming that the foliation fields $\{\mathbf{p}, \mathscr{B}_i\}$ are real physical fields ("ether fields"), one has to insert their energy-momentum density $^{(e)}\mathbf{T}$ ("foliation energy") on an equal footing with the ordinary matter ($^{(m)}\mathbf{T}$), i.e., we put in (2.11)

$$T_{\mu\nu} = {}^{(e)}T_{\mu\nu} + {}^{(m)}T_{\mu\nu} \tag{3.1}$$

By this assumption, the link between matter and geometry is even more intricate than in the traditional framework.

The last task consists in specifying the foliation energy $^{(e)}\mathbf{T}$ in terms of the ether fields. This is done by first deducing second-order wave equations from the first-order dynamics (2.3a) and (2.3b) and then equipping the ether fields with that energy-momentum density **T** which is provided by the canonical formalism for the solutions of those wave equations. The latter are found to be of the Klein–Gordon type, i.e.,

$$\nabla^{\mu}\nabla_{\mu} p_{\nu} = -\mathscr{M}^{2} p_{\nu} \tag{3.2a}$$

$$\mathscr{D}^{\mu}\mathscr{D}_{\mu}\mathscr{B}_{i\nu} = -\mathscr{M}^{2}_{ij}\mathscr{B}^{j}{}_{\nu} \tag{3.2b}$$

Here the masses turn out to be space-time dependent via the $SO(3)$ gauge vectors $\mathbf{C}$ and $\mathscr{H}$,

$$\mathscr{M}^2 := \mathscr{H}_{i\mu}\mathscr{H}^{i\mu} \tag{3.3a}$$

$$\mathscr{M}_{ij}^2 = \mathscr{H}_{i\mu}\mathscr{H}_j{}^{\mu} + C_{i\mu}C_j^{\mu} - g_{ij}(C_{k\lambda}C^{k\lambda}) \tag{3.3b}$$

For the deduction of the Klein–Gordon equations (3.2a) and (3.2b) from the foliation dynamics (2.3a) and (2.3b) the Hubble vector $\mathscr{H}$ must have vanishing divergence:

$$\mathscr{D}_{\mu}\mathscr{H}_i^{\mu} = 0 \tag{3.4}$$

and further is required to be proportional to the gauge vector $\mathbf{C}$:

$$C_{i\mu} = \zeta\mathscr{H}_{i\mu} \tag{3.5}$$

Obeying a wave equation with causal propagation, any one of the three fields $\mathbf{p}$, $\mathscr{B}_i$, and $\mathbf{A}_i$ will contribute to the total foliation energy ${}^{(e)}\mathbf{T}$:

$${}^{(e)}\mathbf{T} = {}^{(p)}\mathbf{T} + {}^{(\mathscr{B})}\mathbf{T} + {}^{(F)}\mathbf{T} \tag{3.6}$$

The ether part is specified here by the canonical formalism as

$${}^{(p)}T_{\mu\nu} + {}^{(\mathscr{B})}T_{\mu\nu} = \frac{1}{2\pi c^2} C^i{}_{\mu} C_{i\nu} \tag{3.7}$$

when the first-order dynamics (2.3a), (2.3b) is applied; furthermore, the gauge field contribution is, as usual,

$${}^{(F)}T_{\mu\nu} = \frac{1}{4\pi}\left(F^{i\lambda}{}_{\mu}F_{i\lambda\nu} - \tfrac{1}{4}F^{i\rho\sigma}F_{i\rho\sigma}\right) \tag{3.8}$$

Now the interesting point here is that the ether contribution (3.7) becomes a pure stress tensor if the gauge vector $\mathbf{C}$ is chosen appropriately. For instance, the choices

$$C_{i\mu} \to -\phi\mathscr{B}_{i\mu} \tag{3.9a}$$

$$\mathscr{H}_{i\mu} \to -\varphi\mathscr{B}_{i\mu} \tag{3.9b}$$

with

$$\mathscr{B}_{i\mu}\partial^{\mu}\varphi = \mathscr{B}_{i\mu}\partial^{\mu}\phi = 0 \tag{3.10}$$

yield a homogeneous and isotropic universe developing a *negative ether pressure*, i.e.,

$$\{{}^{(\mathrm{P})}T_{\mu\nu}+{}^{(\mathscr{B})}T_{\mu\nu}\}\to+\frac{\phi^2}{2\pi c^2}\mathscr{B}_{\mu\nu}\qquad(\mathscr{B}_{\mu\nu}:=G_{\mu\nu}-p_\mu p_\nu\equiv\mathscr{B}^i{}_\mu\mathscr{B}_{i\nu})\quad(3.11)$$

As mentioned above, this fact signals the occurrence of inflation within the present framework.

4. EXPANDING UNIVERSE

For a closer inspection of such a universe, one has to supplement the ether energy-momentum (3.11) by the gauge field part ${}^{(\mathrm{F})}\mathbf{T}$ of (3.8). The latter energy-momentum tensor acquires the usual shape of an ideal gas of massless particles [$SO(3)$ gauge bosons]

$${}^{(\mathrm{F})}T_{\mu\nu}=\frac{f_\perp^2+f_\parallel^2}{8\pi}(3p_\mu p_\nu-\mathscr{B}_{\mu\nu})\qquad(4.1)$$

when the following ansatz for the curvature $\mathbf{F}$ is used:

$$F_{i\mu\nu}=f_\parallel\varepsilon_i{}^{jk}\mathscr{B}_{j\mu}\mathscr{B}_{k\nu}+f_\perp(\mathscr{B}_{i\mu}p_\nu-\mathscr{B}_{i\nu}p_\mu)\qquad(4.2)$$

Here the scalars $f_\parallel$, $f_\perp$ are coupled to the previous fields ϕ, φ of (3.9a) and (3.9b) via the $SO(3)$ Bianchi identity

$$\mathscr{D}_\lambda F_{i\mu\nu}+\mathscr{D}_\mu F_{i\nu\lambda}+\mathscr{D}_\nu F_{i\lambda\mu}=0\qquad(4.3)$$

This coupling is expressed as

$$f_\parallel=\frac{\sigma}{\mathscr{R}^2}+\phi^2\qquad(4.4a)$$

$$f_\perp=\phi\varphi-\dot\phi\qquad(4.4b)$$

where the dot denotes differentiation with respect to universal time θ, i.e.,

$$\dot\phi:=\frac{\partial\phi}{\partial\theta}\qquad(4.5)$$

$\mathscr{R}$ is the "radius" of the universe, and the foliation index σ specifies the type of subgeometry of the 3-dimensional "absolute space" $\theta=\text{const}$ ($\sigma=0$: flat,

$\sigma=+1$: open, $\sigma=-1$: closed universe). Clearly, the line element of the 4-geometry is, as usual,

$$ds^2=d\theta^2-\left(\frac{\mathscr{R}}{\mathscr{R}_*}\right)^2 dl^2_{(\sigma)} \qquad (\mathscr{R}_*=\text{const}) \tag{4.6}$$

where $\mathscr{R}$ is related to the scalar φ of (3.9b) by

$$\varphi=-\frac{\dot{\mathscr{R}}}{\mathscr{R}} \tag{4.7}$$

and $dl_{(\sigma)}$ is the intrinsic line element of the absolute 3-space.

Evidently, the homogeneous and isotropic universe may be effectively described by two parameters: the radius $\mathscr{R}$ and the scalar field ϕ. Thus, the expansion dynamics of such a universe is specified by the equations of motion for these two variables, i.e., by the Yang–Mills–Higgs equations (2.7) and by the Einstein equation (2.11), where for the latter the energy-momentum density ${}^{(m)}\mathbf{T}$ of ordinary matter is chosen to be due to a perfect fluid:

$${}^{(m)}T=\mathscr{M}p_\mu p_\nu-\mathscr{P}\mathscr{B}_{\mu\nu} \tag{4.8}$$

For the subsequent investigations of the expansion dynamics it is convenient to rescale the relevant variables in the following way:

$$\begin{aligned} r&:=\frac{\mathscr{R}}{L_P}, \qquad s:=\mathscr{R}\cdot\phi \\ t&:=\frac{\theta}{L_P}, \qquad m:=L_P^4\mathscr{M} \\ b&:=L_P^4\mathscr{P}, \quad \Lambda:=\frac{L_P}{c} \end{aligned} \tag{4.9}$$

By these arrangements, the Yang–Mills–Higgs equation reads

$$\frac{d}{dt}(r\dot{s})=2rs\left(\Lambda^2-\frac{\sigma+s^2}{r^2}\right) \tag{4.10}$$

Further, the Einsteinian $\mathbf{E}$ may be deduced from the Riemannian $\mathbf{R}$ of (2.8a)–(2.8c) by use of the Hubble vector $\mathscr{H}$ of (3.9b) and the subcurvature

F of (4.2) and then the Einstein equations (2.11) are found to be equivalent to the following system:

$$r\ddot{r}+\dot{s}^2=3\Lambda^2 s^2-\left(\frac{\sigma+s^2}{r}\right)^2-4\pi r^2(b+\tfrac{1}{3}m) \tag{4.11a}$$

$$\dot{m}+3\frac{m+b}{r}\dot{r}=\frac{3\Lambda^2}{2\pi}\left(\frac{s^2}{r^3}\dot{r}-\frac{s}{r^2}\dot{s}\right) \tag{4.11b}$$

(the dot here denotes differentiation with respect to rescaled time t). For an actual numerical integration of the dynamical system (4.10)–(4.11), the initial value $m|_0$ of the mass density m must be related to the other initial values $r|_0$, $s|_0$, $\dot{r}|_0$, and $\dot{s}|_0$ through the so-called "initial-value equation"

$$\dot{r}^2-\dot{s}^2=\sigma+\left(\frac{\sigma+s^2}{r}\right)^2+\frac{8\pi}{3}r^2 m \tag{4.12}$$

The present theory is reduced to the standard model for $\sigma=0$ and $s\equiv 0$. The empty universe ($m=b\equiv 0$) has already been considered for $\sigma=0$ in a preceding paper (Mattes and Sorg, 1989*a*). Here, the main result is that the present model admits a nontrivial vacuum geometry (de Sitter universe: $\varphi=1/l$, $\phi=1/L$; l, $L=$const). It therefore provides us with a physical explanation of the so-called "cosmological term" which originally was introduced into the theory for purely formal reasons. Moreover, the expansion dynamics (4.10)–(4.12) admits two further solutions ($\sigma=\pm 1$) for the empty universe, where the expansion is continued forever in the open case ($\sigma=+1$) and reverts to collapse in the closed case ($\sigma=-1$) after having reached the Planck radius $r_{\max}=1$ as the maximal extension occurring at Planck time $t_P=1$ (Mattes and Sorg, 1989*b*; Mattes, 1990).

5. GENERATION OF MATTER

In the standard matter-dominated model ($b\equiv 0$), the mass M of the universe (resp. the mass content of a comoving 3-cell), is defined through

$$M(r)=r^3 m(r) \tag{5.1}$$

and is a constant (μ, say), however small or large the universe may be. Thus, the traditional gravitation theory fails to give an explanation of the physical origin of the mass density (m) enclosed in the present-day universe. However, the present theory offers a potential source of mass M in the form of the foliation energy emerging through the splitting of the space-time manifold into 3-space and time.

Indeed, introducing the total energy **T** of (3.1) into the Einstein equations (2.11) merely yields the conservation of the *sum* of foliation and matter energy, i.e.,

$$\nabla_\mu({}^{(e)}T^\mu{}_\nu + {}^{(m)}T^\mu{}_\nu) = 0 \tag{5.2}$$

so that both kinds of energy may be converted into one another. This signals the possibility that the primordial universe began with no matter ($M=0$) and built up the present mass through the conversion of foliation energy, which was preexistent as early as the foliated space-time itself. This implies that the variable s started with nonzero value and dropped to zero during the early history of the universe so that the standard model ($s\equiv 0$) is a fairly good approximation today.

The mass density generated by this process is found by integrating equation (4.11b), which yields for zero pressure ($b\equiv 0$)

$$M(r) = \mu + \frac{3\Lambda^2}{4\pi}\left(3\int_0^r s^2\,dr - rs^2\right) =: M_{\mathrm{ad}} + M_{\mathrm{na}} \tag{5.3}$$

Here, the integration constant μ is identical to the *adiabatic* M_{ad} part not subject to the energy-exchange process between matter and "ether;" this term gives rise to the well-known r^{-3} divergence of the density m for vanishing size of the universe ($r\to 0$):

$$m_{\mathrm{ad}} = \frac{\mu}{r^3} \tag{5.4}$$

Clearly, it is very tempting to let this term vanish ($\mu\to 0$) so that the total mass M of (5.3) exclusively consists of its *nonadiabatic* part M_{na},

$$M_{\mathrm{na}} = \frac{3\Lambda^2}{4\pi}\left(3\int_0^r s^2\,dr - rs^2\right) \tag{5.5}$$

which just represents the converted foliation energy. In this way, the universe starts with zero matter and zero radius, but the ultimate mass M at later times, when the field variable s has died out, is given through

$$M \equiv M_{\mathrm{na}} \to \frac{9\Lambda^2}{4\pi}\int_0^r s^2\,dr \tag{5.6}$$

(see Figure 1). Of course the time scale for such "creation *ex nihilo*" is expected to be governed by the Planck time θ_{P} ($\approx 10^{-43}$ sec), where the generation of matter has to be adequately described in terms of an appropriate quantum theory of the interaction of the ether fields $\mathbf{p}$, $\mathscr{B}$ with the corresponding particle fields. However, even in the absence of such a detailed

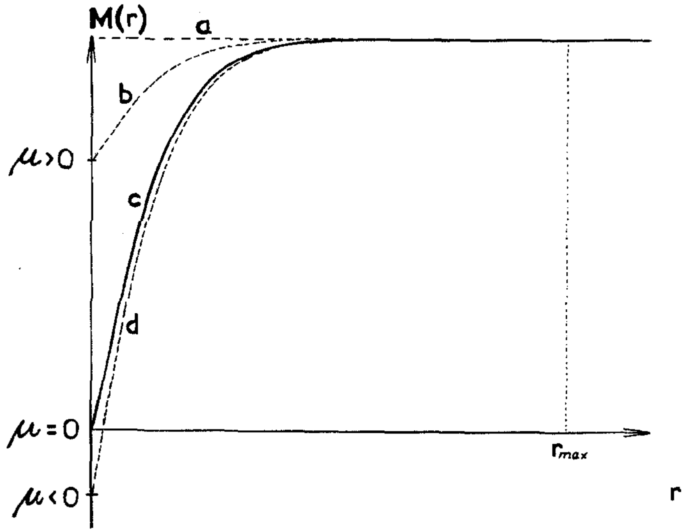

Fig. 1. Conversion of foliation energy for a closed ($\sigma = -1$), matter-dominated universe ($b \equiv 0$), $\Lambda = 1.5$. For the time-symmetric solutions of the equations of motion (4.10)–(4.12) the total mass $M(r)$ of (5.3) assumes its adiabatic value μ for vanishing size $r \to 0$. The standard solutions (a), corresponding to the standard model ($s \equiv 0$), have constant mass throughout ($M \equiv \mu$). For appropriate choice of the initial value $s|_0$ at maximal radius $r_{\max}$, the adiabatic part μ vanishes: "creation *ex nihilo*" (c). In general, the mass M consists of both the adiabatic and nonadiabatic parts (b). Negative values for $\mu \equiv M(0)$ also occur (d) when $s|_0$ is chosen too large.

microscopic picture, some global properties of the early universe may approximately be accounted for by the classical description (Figure 2).

6. INFLATION

The reason the classical picture should not be too bad is due the very early decoupling of the gravitational interactions from the particle creation/annihilation process occurring during the primordial quantum phase. Therefore the space-time geometry may be assumed to develop in a purely classical way even when the other interactions are still governed by their corresponding quantum dynamics. However, there is some problem because if one imagines the primordial universe being born by some quantum effect, the relevant physical scale should be set by the Planck mass M_P ($\approx 10^{-5}$ g) or the Planck length L_P ($\approx 10^{-33}$ cm). If these parameters are realistic measures also for the time of gravitational decoupling, there must have taken place some strange effect during the subsequent classical stage, which was able to

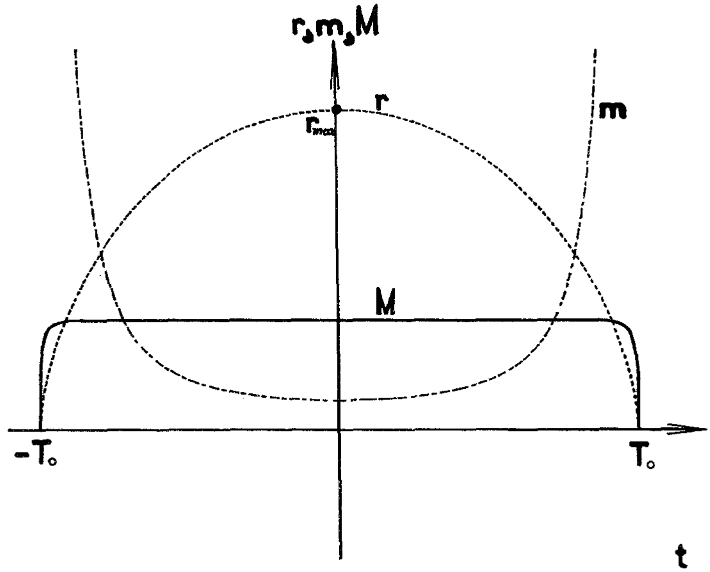

Fig. 2. Creation *ex nihilo*. The closed universe ($\sigma = -1$) starts with zero matter ($\mu = 0$, Figure 1) but rapidly attains its mass M by conversion of foliation energy. The mass M is then held constant during the "standard stage" beyond the Planck time, where $s \approx 0$, and the standard model becomes a good approximation. Choice for the numerical integration: $r_{max} \equiv 5$, $\dot{r}|_0 = 0$, $m|_0 = 4.6 \times 10^{-3}$, $s|_0 = 3 \times 10^{-8}$, $\dot{s}|_0 = 0 \rightsquigarrow$ lifetime $2T_0 \approx 8$.

blow up the universe and thereby equip it with the right initial condition for the simple expansion law predicted by standard FRW models.

In order to take account of such a peculiar inflation, the current scenarios of cosmic evolution introduce an extra physical system, namely a weakly coupled scalar field which is subject to the Higgs mechanism. However, it seems to us more adequate to consider inflation as being produced by gravitation itself without reference to such an additional physical system (e.g., a matter field to be equipped with all the necessary properties for inflation in an artificial manner). Indeed, we are able to show that our present gravitation theory admits solutions of inflationary character in a very natural way; one could even argue that our model predicts inflation as the natural state of motion for the universe. The recollapsing solutions of the type shown in Figure 2 then appear as intermediate states ("vacuum fluctuations") of finite duration between two vacuum configurations, the initial (final) one of which is a contracting (expanding) de Sitter state (Figure 3).

As mentioned after (4.12), the flat de Sitter universe ($\sigma = 0$) is one of the exact vacuum solutions ($m = b \equiv 0$) of the theory. But also for nonflat

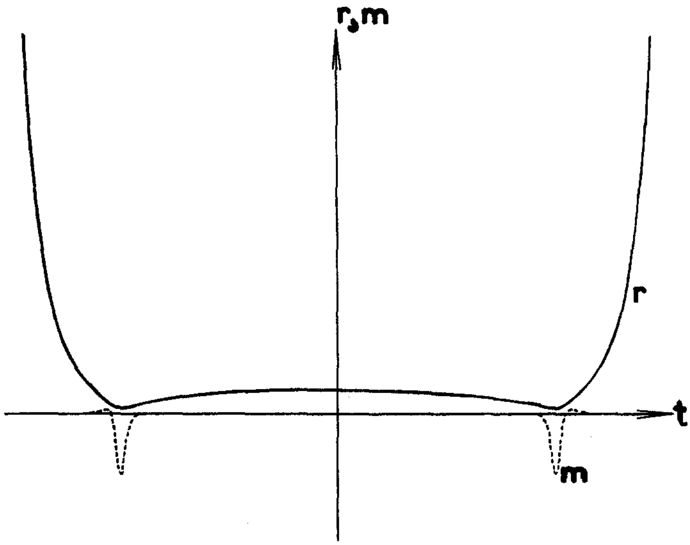

Fig. 3. Matter-dominated universe as vacuum transition. Since the *contracting* de Sitter vacuum ($l>0$) is unstable, the transition to the stable (expanding) phase ($l<0$) is possible only by intermediately passing through a "standard stage" with almost constant mass M (see Figure 2). The mass density m has to become negative for a short time interval connecting the qualitatively different phases.

foliations ($\sigma \neq 0$), both the contracting and expanding de Sitter geometries are approximate solutions so long as the field variable s is much larger than the foliation index ($|s| \gg |\sigma|$). Clearly, this condition is satisfied almost trivially on account of the exponential growth (decay) of s. Moreover, it can easily be shown that the contracting de Sitter phase is unstable, whereas the expanding one is found to be stable (Mattes and Sorg, 1989*b*). Thus, one may consider the intermediate state of Figure 3, which is assumed to resemble very much our observable world, as an unavoidable stage of the evolution of the real universe, when it tries to leave its initial (but unstable) vacuum state in order to pass over to the stable vacuum phase.

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