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A NEW COSMOLOGICAL SCENARIO

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Along the last fifteen years, the scientific community has witnessed the complete domination, within the context of Cosmology, of the idea of a singular Universe, arising from an explosive beginning at a certain instant of creation.

The alternative proposal of an Eternal Universe, without beginning or end and thus without singularities, fell out of use due to the formal entanglements it get involved with when confronting the theoretical strenght of the so-called "singularity theorems" of the early Seventies, on the one hand, and to the phenomenological issues that an infinite past may cause, on the other. For instance, how could one prevent the total colapse of matter in an infinitely old Universe; how to preclude an infinite entropy, etc ?

It is clear that formal and phenomenological difficulties of a similar kind have also plagued the standard explosive model; neverthless, enormous efforts have been undertaken lately attempting to heal some of the troubles associated with singular Universes, whereas the problems concerning eternal Universe models have deserved no further attention. This unmatching, which is far from being settled upon a rational procedure, seems to stem from an emotional rather than a logical attitude.

The aim of the present work is to resume an alternative line of research in order to devise solutions for some shortcomings of eternal models, thus reducing the artificial gap which now exists between the two global views of the world.

The first hindrance to be surmounted in the accomplishment of this task is the very attainment of one such eternal Universe. It is well-known that singular regions shall appear in every cosmic solution of Einstein's equations if spacetime curvature originates from matter which behaves in the manner of a perfect fluid. Besides this regularity in the behaviour of matter, the so-called singularity theorems demand, to ensure their proper utilization, other formal requirements which are far from being unequivocally fulfilled in the actual world. It is not our concern, however, to examine them in detail here. It suffices, for our present purpose, to show that one is able to generate an eternal Universe without resorting to odd-behaving matter or any other kind of exceptional situation.

We begin with the observation that, at the basis of every singularity theorem, there exists an evolution equation relating the world's matter distribution with some function of a typical property of spacetime curvature. In many cases, this equation corresponds to some variant of Raychaudhuri's equation, connecting the temporal dependency of the cosmic expansion θ (= $\frac{d}{dt}$ ln volume) to the energy density of the Universe. Once such an equation is owned it is then possible to associate the existence of a singularity to the fact that, for any arbitrary observer endowed with a four-velocity V^{μ} (such that $V^{\mu}V_{\mu} > 0$), the inequality $R_{\mu\nu}V^{\mu}V^{\nu} < 0$ is valid. This relation would guarantee, thus, that somewhere in the world a singular region should occur. But this inequality may not hold if the matter content of the Universe, or better, if the main responsible for the curvature of spacetime were identified, for instance, to a physical field coupled non-minimally to gravitation. In this case, the validity of Raychaudhuri's equation does not allow conclusions about the inevitability or not of the existence of singularities in a generic solution.

The next step, then, would consist in the exhibition of viable examples of such couplings. Curiously, it was mainly due to the intensive study on couplings of scalar fields with gravitation, carried out in the last decade, that the scenario cleared up and some misconceptions of old were abandoned. Elementary particle physics, for instance, led some scientists to realize the importance of conformal couplings, which became better appreciated in virtue, chiefly, of the scale invariance displayed by high-energy processes. Furthermore, the success achieved by the mechanism of spontaneous symmetry breaking of, say, a scalar field ϕ, associated in Lagrangean formalism to a quartic term $\sqrt{-g}\ \phi^4$, and the fact that such term exhibits conformal invariance, have made physicists ready to accept with ease the idea that rather than being avoided, conformal coupling may, on the contrary, have the preference of Nature. In this manner , the acknowledgement of conformal coupling as one of the possible processes of non-minimal interaction has induced quite naturally to the utilization of such types of coupling, thus resulting eliminated — at least in principle — a conceptual restriction that physicists had got accostumed, due to tradition.

In order to show a simple case of which an analytical solution is thoroughly known, allowing the generation of a non-singular, spatially homogeneous cosmological model, let us consider the theory of the non-minimal coupling of a vector field W_μ with gravity described by the Lagrangean

$$L = \sqrt{-g}\ [-\frac{1}{4} f^{\mu\nu} f_{\mu\nu} + \beta R W_{\mu} W^{\mu} + \frac{1}{k} R]$$

in which β is a constant and, as usual,

$$f_{\mu\nu} = W_{[\mu,\nu]} \quad .$$

In references (1,2) it is exhibited a solution of a Friedmann-like Universe,

$$ds^2 = dt^2 - A^2(t)\ d\sigma^2 \ ,$$

where the radius of the Universe A(t) is never null:

$$A(t) = \sqrt{t^2+p^2} \quad ,$$

p being a constant.

This Universe, curiously, has as assymptotic limits (at the infinite past and infinite future) the empty Minkowskii Universe. Though this solution be isotropic, and have also properties similar to those displayed by the standard Friedmann model at its regular points, it indeed possesses the non-singular characteristic which we intended to show.

In this way, it is not difficult that some dynamical structure associated to a non-minimal coupling may be able to produce, in less symmetric cases, non-singular models comprising more general features, for instance, anisotropies.

Our new cosmic scenario starts precisely with the assumption that in an earlier stage of the world evolution, when the Universe was experiencing a contracting epoch, the basic structure of spacetime was highly anisotropic.

The idea that the Universe would have passed through a less regular phase, even a chaotic one, with a high degree of anisotropy was developed by several authors. In fact, it involves a certain aspect of initial arbitrariness that is surely very attracting for any non-finalist description of the cosmos. Besides it can provides solutions for some embarrassing features of the standard model. For example, it is extremely difficult to reconcile the remarkably large rates of isotropy observed with the existence — in the standard model — of horizons which would have prevented an efficient information exchange among distinct regions, thus averting the condition for that spatial uniformization to occur.

What seems to have striked a severe blow on the conception of a chaotic,"mixmaster"-type Universe was the physicist's inability in furnishing models efficient enough in cancelling out, after a reasonable time span, an eventual initial anisotropy. In the scenario we are presenting here, this anisotropic phase would have occured in a previous contracting epoch of the Universe, which after achieving a (non-singular) maximum contraction instant would become to expand, entering into our present expanding epoch. We are not concerned here in accompanying analytically such change; we have seen above that it is possible to elaborate physically acceptable mechanisms which are able to induce this passage from the colapsing phase to the expanding one. Let us then concentrate upon a single problem: how could we eliminate that large initial anisotropy ?

In order to produce such an elimination process we will make use of some ideas of L. Landau, concerning his studies about the evolution of matter behavior according to continuous temperature changes. Global spacetime curvature has its origin in the cosmic distribution of the matter which pervades the cosmos. This matter is usually characterized as a fluid and, in the majority of cases, as in the standard model for instance, it is taken to be a perfect gas. In recent years, a quantum treatment has been endeavoured, as well as the examination of viscous, large-scale entropy generating processes.

For our model, we will treat the cosmic fluid as an structure capable of being globally characterized by a mixture of liquid and crystalline, quasi-solid properties, almost as if these were unified - associating them to properties similar to those presented by a liquid-crystal — and thus we will identify the "crystalline" phase to a more ordered, less symmetric (nematic) stage and the "liquid" one to a less ordered, more symmetric structure. Hence, following an analogy with the treatment given to matter by Landau, we shall accept that it is possible to define,throughout the Universe, a macroscopic parameter of order ξ_{ij}. The tensorial character of this parameter is due precisely to the aim of describing the evolution of the anisotropy, which can then be specified either by the kinematical (via the shear σ_{ij}) or the dynamical (via the anisotropic pressure π_{ij}) structure of the problem.

Parameter ξ_{ij} is such that an isotropic more symmetric phase is characterized by the value $\xi_{ij} = 0$, while an anisotropic, more ordered phase corresponds to $\xi_{ij} \neq 0$.

The question we are interested in solving is this: how the Universe could have passed from a preliminary anisotropic phase ($\xi_{ij} \neq 0$) to the present highly isotropic one ? What type of physical mechanism would have made possible such a delicate passing ? Following Landau[3] we will examine the behaviour of a thermodynamical potential, e.g, the free-energy F. We may then consider an enlargement of the functional dependence of F with volume V and temperature T, allowing F to be also dependent of the macroscopic order parameter $\xi_{ij} = \hat{\xi}$. In this way, F must comprise the necessary information in order to express, through its extremal behaviour, the change from the nematic phase (N) to the isotropic one (I).

Hence, taking into consideration that Tr $\sigma_{ij} = 0$ and Tr $\pi_{ij} = 0$, it follows that Tr $\hat{\xi} = 0$ and so the functional dependence of F may be described by means of the series[4]

$$F(V,T,\hat{\xi}) = F_0(V,T) + \alpha\, Tr(\hat{\xi})^2 + \beta\, Tr(\hat{\xi})^3 + \gamma\, [Tr(\hat{\xi})^2]^2 + \ldots$$

Since our aim is the examination of the passage from phase N to phase I, in an attempt to devise an efficient isotropization mechanism, we shall limit our present discussion to a simple kind of planar anisotropy. Thus, we will consider that β and γ are constants and that the term α is the only one to display an explicit dependence on the temperature. It is clear that, besides this dependence of thermodynamical origin, curvature effects must also appear. Hence, we write

$$\alpha = a^2\, (T-T_c) \quad .$$

For planar anisotropy we can also write

$$\hat{\xi} = \frac{\sigma}{2} \begin{pmatrix} -1 & & \\ & -1 & \\ & & 2 \end{pmatrix}$$

and consequently the condition of existence of a minimum (distinct from $\sigma = 0$) for the free energy must be a function of the temperature. Thus, one finds that if $T < T_c + \frac{3}{32}\frac{\beta^2}{a^2\gamma}$, there will exist an anisotropic phase for the system; if,otherwise, we have $T > T_c + \frac{3}{32}\frac{\beta^2}{a^2\gamma}$, only the isotropic phase survives, with allowance for eventually coexisting intermediary phases. In this way, there exists a temperature $T_{NI} = T_c + \frac{1}{12}\frac{\beta^2}{a^2\gamma}$ such that it corresponds to a net separation between the anisotropic and isotropic phases (critical temperature).

In a more general case, the critical temperature T_{NI} could be also dependent on the global spacetime curvature. In this circunstance, it is not absurd to think that the phase transition mechanism allowing the isotropization of the Universe could be related to the process that precludes the appearance of singularities, thus providing for an unification of both problems and characterizing the transition temperature as the maximum temperature achieved by the cosmos.

The passage through the transient phase, in which both the "crystaline" and the "liquid" phases coexist, in association with the temperature increase due to the diminishing of the radius of curvature of the Universe, causes an entropy variation which is directly proportional to T_{NI}. In effect, from the expression $S = -\frac{\partial F}{\partial T}$ for the system's entropy it follows that $\Delta S = \frac{2a^3}{\gamma} T_{NI}$.

We thus see that the smaller the radius of curvature corresponding to the point of maximum collapse is, the larger the entropy produced. This process may generate, in this way, a large amount of entropy, due to the fact that the transition temperature can be very high.

Though the model presented here be still very crude, it brings forth an alternative proposal with respect to the conventional explosive Universe models that seems to deserve a greater attention.

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