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FORMATION OF STRUCTURES IN THE VERY EARLY UNIVERSE

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ABSTRACT

~~We sketch~~ An alternative picture of cosmological phase transition is sketched and ~~study~~ its implications to the formation of structures in the very early Universe is studied. ~~We~~ It is shown that the condensation of walls at high temperatures leads to fluctuations which are in accordance to all necessary conditions to the formation of structures in the Universe. Furthermore the number of aglutination centers is roughly equal to the numbers of great structures observed in the Universe today.

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INTRODUCTION

After reaching some remarkable successes such as the prediction of the microwave cosmic background radiation, the quantity of primordially synthetysed light nuclei, and with the Grand Unification Theories being able to explain the net predominance of matter over antimatter in the Universe, the Big Bang Standard Cosmology seems to face two categories of difficulties. On one hand the cosmological constant problem(1) that urges for a solution, on the other, conundrums such as the isotropy-homogeneity(2), horizon(3), flatness or age of the Universe(4) and even the excess of magnetic monopoles(5) which would have been produced in the very early stages of the Universe, that are all solved by the Inflationary Cosmology in its two versions(6,7). This model that is based in the existence of a phase in the history of the Universe dominated by the vacuum energy density, actually makes the cosmological term suggested by finite temperature field theory to be an essential ingradient of Cosmology, rather than a problem. It is worth pointing out that some suggestions which consider the quantum gravitational effects during the "Planck Era" have some potentiality to solve the mentioned problem in a unified manner(8). Besides, the work of Starobinskii(9) shows an alternative possibility of using the cosmological constant to isotropise the Universe.

The purpose of this work is to outline some non orthodox ideas which can give some insight into the solution of the first category of difficulties with some other interesting consequences such as the solution of the domain walls problem(10) and suggest a consistent mechanism to generate barionic structures in the Universe. As the key point of this proposition is based on an alternative approach to this study of the Cosmological Phase Transition, we will sketch our new methodology parallel to the traditional point of view on the topic[11]. The discussion will be brief and the cosmological consequences will be presented reviewing some well known facts.

I. PHASE TRANSITIONS IN FIELD THEORY

1. EFFECTIVE POTENTIAL METHOD

Phase transitions in field theory are studied bearing in mind that the theories which describe fundamental interactions among elementary particles, are spontaneously broken throughout the development of a non-zero expectation value of the fields in the vacuum state.

Let us illustrate with the simplest possible model the real scalar field with self-coupling ϕ^4 and wrong sign for the mass term. Its Lagrangian density is*:

$$L = \frac{1}{2}(\partial_\mu \phi(x))^2 + \frac{1}{2}\mu^2\phi^2(x) - \frac{1}{4} g\, \phi^4(x) \qquad (1)$$

and has the discrete symmetry $\phi(x) \to -\phi(x)$. The extremal values for $V(\phi)$ are:

$$\phi = 0 \quad \text{(unstable)} \qquad (2)$$

$$\phi = \pm\sqrt{\frac{\mu^2}{g}} \qquad (3)$$

therefore one has to have a nonvanishing vacuum expectation value of ϕ,

$$\langle 0|\phi(x)|0\rangle = \pm\sqrt{\frac{\mu^2}{g}} \equiv \sigma \qquad (4)$$

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*The unit system $\hbar = c = k_B = 1$ [illegible] adopted.

The perturbation theory must be built up in terms of creation and annihilation operators of the field quanta, so that the latter annihilates the vacuum. So we define

$$\phi'(x) = \phi(x) - \langle 0|\phi(x)|0\rangle \qquad (5)$$

which breakes the $\phi(x) \to -\phi(x)$ symmetry when replaced in (1).

Classicaly, the field energy density is given by:

$$H(\phi,\pi) = \frac{1}{2}\pi^2 + \frac{1}{2}(\nabla\phi)^2 + V(\phi) \quad . \qquad (6)$$

The spontaneous symmetry breakdown that occured may be understood in terms of energy because from (6) the configuration $\phi = c$ (4) is less energetic than the configuration $\phi = 0$ (3), being thus preferable to it.

Quantum effects might introduce significant corrections to the results discussed above (based on the classical energy (6)). At the Quantum level we should look for the minima of the effective potential which generates all one particle irreducible graphs (1PI) at zero momenta. That is

$$\Gamma(\phi) = \sum_n \frac{1}{n!}\Gamma^{(n)}(0\ldots0)\,\phi^n \quad .$$

Actually, we compute explicitly only the first Quantum corrections which are obtained by summing up the one loop graphs.

The generalization to finite temperature through the extension of the usual Feynman rules ($\int dk_0 \to 2\pi T \sum_{n=-\infty}^{\infty}$ and so on) leads to the idea of phase transitions[11]. That happens so because the minima of the effective potential is now temperature dependent $\sigma = \sigma(T)$ (thus playing the role of an order parameter) and it gets smaller as temperature increases and vanishes above a certain temperature - T_c - thus leading to symmetry restoration.

2. ALTERNATIVE METHOD FOR THE STUDY OF PHASE TRANSITIONS

Model (1) admits the existence of macroscopic solitons. These solutions interpolates between different vacua of the theory, and consequently divide the space into domains, functioning therefore as Bloch walls.

At first sight one has the impetuous of discarding these solutions since the partition function associated to such a configuration is proportional to $\exp - \frac{EA}{T}$ where A is the soliton area and E the energy per unit area, and it becomes zero in the thermodynamical limit $(V \to \infty, A \to \infty)$. Consequently the soliton seems not to be thermodynamically relevant. Nevertheless the emergence of a soliton alters the entropy of the system and consequently if we want to decide whether or not a soliton is thermodynamically favored the correct analysis is to consider the free energy associated to such a Bloch wall per unit area, that is

$$f_{wall}(T) = E - Ts(T) \qquad (7)$$

At low temperatures $f_w(T)$ is positive and a Bloch wall will not appear in the system. As the temperature increases the entropy term in (7) takes over the energy term and, in accordance with Peierls arguments, walls will sprout in the system. One then expects that there is a critical temperature

T_c , such that

$$\begin{aligned} &a)\quad T > T_c \qquad f_{wall} < 0 \quad . \\ &b)\quad T < T_c \qquad f_{wall} > 0 \quad . \end{aligned} \tag{8}$$

Expressions (8-b) indicates that configuration with one domain wall is thermodynamically supressed for $T < T_c$ whereas (8-a) means that for $T > T_c$ configurations full of domain walls are favored.

As argued in refs. (12-14), T_c is the critical temperature of the phase transition.

The Hamiltonian density of model (1) is:

$$H = \frac{1}{2}\left(\frac{\partial\phi}{\partial t}\right)^2 + \frac{1}{2}(\nabla\phi)^2 + \frac{g}{4}(\phi^2-\sigma^2)^2 \tag{9}$$

and the solution describing a soliton at rest paralell to the yz plane is

$$\phi(x) = \frac{\mu}{\sqrt{g}} \tan\frac{\mu x}{\sqrt{2}} \tag{10}$$

whose classical energy density is given by:

$$E_{clas} = \int_{-\infty}^{\infty} H dx = \frac{2\sqrt{2}}{3}\frac{\mu^3}{g} \tag{11}$$

(point zero corrections to this energy are proportional to μ^3 and therefore irrelevant to interesting situations in cosmology, e.g., when $T \gg \mu$). It is also good to remember that here we take $g \ll 1$, which is necessary to validate our semiclassical argumentation.

The free energy per unit area of the wall is given by[12]

$$f_{wall}(T) = F_{sol} + F^1(T) - (F_{vac} + F^0(T)) \tag{12}$$

where $F_{sol} - F_{vac} = E$ and $F^1(T)$, $F^0(T)$ are free energies of excitations in the soliton sector, and the free energy in the vacuum sector respectively. It may be shown that in the limit $T >> \mu$ one gets[13,14]

$$f_{wall} = \frac{(\sqrt{2}\,\mu)^3}{3g} - \frac{\mu T^2}{2\sqrt{2}} \quad . \tag{13}$$

The critical temperature refers to the $f_{sol}(T_c) = 0$ situation and so

$$T_c = \sqrt{\frac{8}{3}}\,\frac{\mu}{\sqrt{g}} \tag{14}$$

which is quite close to the critical temperature $T_c = 2\sqrt{\frac{\mu^2}{g}}$ obtained by orthodox procedures[11].

Up to now we have shown that solitons will emerge in the system but nothing has been said on counting them. At first sight one might thing that there will be produced an infinite number of domain walls. However, as pointed in refs. (12),(13),(14) this is not so. In ref. (14) we have shown how to count walls for temperatures very close to T_c. We will repeat here the proposal for counting domain walls discussed in refs. (12) and (13).

The theory is defined for the volume $V = AL = L^3$ and the N^{th} configuration contains 3N solitons (N solitons parallel to each of the volume faces which involve the system).

The system tends to produce many solitons, because they are thermodynamically favoured configurations and that could make it collapse. Collapsing does not occur because of soliton interactions which are supposed to be proportional to the intersections between them, that is, $\alpha\mu^2/gL$ with $\alpha \sim 1$ [15]. If Δ is the distance between neighbouring solitons and $\Delta = L/N$, then the system's free energy of noninteracting walls shall be

$$F_N = 3NA\, f_{wall}(T) = \frac{3L^3}{\Delta} f_{wall}(T) \quad . \tag{15}$$

But, if we take into account interactions occurring in the intersections and remember that there are $3N^2$ intersections to the proposed geometry, we get:

$$F_N^{Int} = 3N^2\, \alpha\, \frac{\mu^2 L}{g} = 3\alpha\, \frac{\mu^2}{g}\, \frac{L^3}{\Delta^2} \tag{16}$$

therefore, the total free energy would be

$$F_N = 3V \left(\frac{f_{wall}}{\Delta} + \frac{\alpha\mu^2}{g\Delta^2} \right) \tag{17}$$

the stability is obtained with $3N_0$ solitons $(3N_0 = L/\Delta_0)$, which minimize (17). It is easy to show that in these circunstances the average distance between neighbouring solitons is given by:

$$\frac{1}{\Delta_0(T)} = \frac{1}{d_0} \left[\left(\frac{T}{T_C} \right)^2 - 1 \right] \tag{18}$$

with

$$d_0 = \frac{3\alpha}{\sqrt{2}\,\mu} \quad . \tag{19}$$

We see that the average distance between the solitons must obviously be greater than their typical width which is approximately $\frac{1}{2}\mu^{-1}$. This fact establishes a limit temperature to the validity of the proposed approach, $T_L \cong (1 + 3\sqrt{2}\,\alpha)^{1/2}\,T_C$,

$$\frac{F_N(T)}{V} = -\frac{3g}{32\alpha}\left[(T)^2 - (T_C)^2\right]^2 \quad \text{for} \quad T > T_C \quad . \tag{20}$$

The energy density of the solitons may easily be calculated by:

$$\rho_{wall} = \frac{E_{wall}}{V} = A\,E_{class}\,\frac{3N_0}{L^3} = \frac{3E_{class}}{\Delta_0} \tag{21}$$

and so by using (18) one gets

$$\rho_{wall}(T) = \frac{\mu^2}{2\alpha}\left[(T)^2 - (T_C)^2\right] \quad T > T_C \quad . \tag{22}$$

The symmetry of the system is recovered at $T > T_C$ because the solitons that come up split the space into regions sometimes with $\phi_v = +\sqrt{\mu^2/g}$, others with $\phi_v = -\sqrt{\mu^2/g}$, so that $\langle\phi\rangle = 0$. The symmetry restoration as a result of condensation of domain walls is easily understood by looking at figure 1-a.

The discussion above can be summarized as follows: this theory describes domain walls (solitons) with a natural thickness $\sim \frac{1}{\mu}$. This means that for $T \gtrsim T_C$ the average distance between two neighbour walls cannot be smaller than $\Delta_0 \sim \frac{1}{\mu}$ (otherwise the solitons are so superimposed that one can no longer speak of domains or domain walls). Then for

$T \sim T_c$ one has an estimate for the number of domains in the system. If the Universe undergoes a supercooling, this number of domains is going to be preserved till the system reaches the lower temperatures, at which it starts decaying and reheating again. Within this picture one then expects that the number of structures in the Universe should be equal to the number of seeds that generate them (which we call aglutination centers). From the countings of domains one can predict the number of aglutination centers. This calculation and others cosmological implications will be discussed next.

II. COSMOLOGICAL IMPLICATIONS

The electromagnetic and weak interactions are nowadays described by a theory which unifies the description of these interactions. The theory of Glashow-Weinberg-Salam makes use of the mechanism of spontaneous breakdown of Gauge symmetries.

It is believed that the electromagnetic, weak and strong interactions may be described althogether by means of a unified theory whose symmetry group is G. In order to get the low energy phenomena described by the group $SU(3) \times SU(2) \times U(1)$ one has to break the symmetry spontaneously.

One can argue easily that theories whose symmetry is spontaneously broken would exhibit symmetry restoration for temperatures higher than the scale at which symmetry is broken. One then expects, if the system is cooled, a phase transition whose critical temperature is of the order of the order parameter at zero temperature $T_c \sim \sigma(0)$.

The very early Universe consisted of a very hot soup of elementary particles whose dynamics was described by these unified theories. As the Universe expands it must have gone under a series of phase transitions (depending on the Unification Group), until it reaches the known low-energy symmetry $SU_c(3) \times U(1)$. That is

$$G_n \to G_{n-1} \to \dots \to G_1 \equiv SU_c(3) \times SU_L(2) \times U_Y(1) \xrightarrow[T \sim 10^2\ Gev]{} SU_c(3) \times U_{E.M.}(1)$$

1. EXISTENCE OF DOMAINS

Unification theories that have $\phi \to -\phi$ symmetry, have regions at a temperature lower than T_c with expectation values as many as $\pm\sigma$ and could therefore be separated by walls. In the Effective Potential Method this fact is a problem because the superficial energy density of a GUT wall(16) is:

$$E_{wall} = \alpha_{GUT} \cdot M_H^3 \sim (10^{44} - 10^{48})\, g\, cm^{-2} \tag{23}$$

and if these walls are expanding as fast as the horizon(17), it follows that a wall would have a size of the order of our present horizon $(d_H(0,t_p))$, that is

$$R_{wall} \sim d_H(0,t_p) \sim 10^{28}\, cm \tag{24}$$

which implies that the energy associated to one wall divided by the energy of Universe is given by:

$$\frac{E_{wall}}{E_{univ}} \sim \frac{E_{class} \cdot d_H^2(0,t_p)}{\rho_c\, d_H(0,t_p)^3} \sim 10^{46} - 10^{50}\ !! \tag{25}$$

where ρ_c is the critical density energy, $\rho_c \cong 10^{-29}\,g\,cm^{-3}$. Therefore, the discrete symmetry cannot be accepted in these approaches (a term $\propto$ Tr ϕ^3 is usually introduced in the Higgs potential so as to break the symmetry by hand, and in consequence forbid the existence of walls). However, walls can be very interesting to the formation of structures in the Universe, as we will see.

Within the alternative approach there is a natural solution to this problem since the walls are the solitons which can appear only above the critical temperature, as discussed above and are forbidden below T_c.

2. THE COSMOLOGICAL CONSTANT PROBLEM

In the usual approach it is possible to show that $\rho_{vacuum} \propto T_c^4$ (11) and considering the GUT and Weinberg-Salam phase transitions, we have:

$$\rho_{vac} \sim T_c^4 \sim \begin{cases} 10^{78}\,g\,cm^{-3} & \text{GUTS} \\ 10^{25}\,g\,cm^{-3} & \text{G.W.S.} \end{cases} \tag{26}$$

In the present the energy density of the vacuum is estimated by supposing that it does not dominate the dynamics of superclusters of galaxies* and so:

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* Another evaluation leading to the same constraint as (27) can be carried out with the values extracted from observations of the Hubble constant (H_p), desacceleration parameter (q_p) and the density parameter ($\Omega \equiv \frac{\rho}{\rho_c}$). It is possible to show(18) that at present

$$\Omega p = 2q_p + \frac{2\lambda}{3H_p^2} \quad , \quad \text{where} \quad \lambda \equiv 8\pi G\,\rho_{vacuum} \quad .$$

$$\rho_{vac} < \rho_{sc} \sim 10^{-29}\,g\,cm^{-3} \quad (27)$$

then, assuming that ρ_v saturates the bound in (27) one gets

$$\frac{\rho_{vGUT}}{\rho_{vac}} \sim 10^{107} \quad \text{or} \quad \frac{\rho_{v\,W.S.}}{\rho_{vac}} \sim 10^{50} \;!!! \quad (28)$$

and these huge differences have no explanation within this point of view.

In the alternative approach the energy density of the condensate of walls may be interpreted as a "cosmological constant" and as we have seen, the contribution of solitons is small and tends to zero below the critical temperature according to (22).

3. FORMATION OF STRUCTURES IN THE VERY EARLY UNIVERSE

The standard cosmology based on Friedmann's model assumes that matter and radiation have been homogeneous and isotropically distributed during all the history of the Universe. Consequently the formation of nowadays observed structures of the Universe such as galaxies, clusters of galaxies and superclusters, demands the occurrence of small fluctuations in the uniform energy density.

Lifshitz[19] has shown that density and pressure perturbations in an expanding Universe increase in accordance to a power law with time t ,

$$\frac{\delta\rho}{\rho} \sim t^n \quad (29)$$

as long as the perturbations are greater than a critical length, which is called Jeans' length ($\lambda > \lambda_J$) :

$$\lambda_J = v_s \left(\frac{\pi}{G\rho}\right)^{1/2} \tag{30}$$

where v_s is the speed of sound in the determined medium given by the well known expression in terms of the derivative of the pressure (p) with respect to the density (ρ)

$$v_s = \left(\frac{\partial p}{\partial \rho}\right)^{1/2} \quad . \tag{31}$$

The perturbations become effective when they enter into the horizon, i.e., in region casually connected, that is:

$$\lambda_J(t) < d_H(0,t) \quad . \tag{32}$$

For a Universe dominated by radiation ($\rho \propto T^4$) , $P = \rho/3$, $v_s = 1/\sqrt{3}$ (c=1) , so that:

$$\lambda_J \sim d_H(0,t) \tag{33}$$

and besides, the photonic viscosity due to Thomson's scattering freezes the fluctuations, not permitting them to increase. Consequently, the gravitational instability mode is only triggered after the recombination when the Universe has its energy density dominated by non relativistic matter. Assuming that in the latter situation matter behaves as an ideal gas ($p = \rho T$, $p << \rho$) , then it follows that:

$$\lambda_J = 2.9 \times 10^{19} \, \Omega p^{-1/2} \text{ cm} \tag{34}$$

where $\Omega = \rho/\rho_c$. The corresponding mass (Jeans' mass) is given in terms of the solar mass $M_\odot$ by:

$$M_J = \frac{4\pi}{3} \rho_{rec} \lambda_J^{\cdot} \cong 10^5 M_\odot \Omega_p^{-1/2} \tag{35}$$

that is very close to the mass of globular clusters[20], nevertheless inferior to the known spectrum of galactic masses M_G, $10^6 M_\odot \lesssim M_G \lesssim 10^{12} M_\odot$.

The magnitude of the primordial density fluctuations was established by Zel'dovich[21] throughout the compatibility with the barion-photon ratio that is presently evaluated as $r = (n_B/n_\gamma)_p \sim 10^{-9\pm1}$ with temperature fluctuations observed in cosmic microwave background radiation ($\delta T/T \sim 10^{-4}$) and with the quantity of primordially synthetised elements (consistent with r),

$$\left(\frac{\delta\rho}{\rho}\right) \sim 10^{-4} \quad . \tag{36}$$

On the other hand, density fluctuations may be:

1) Isothermal ($\delta T/T = 0$), when only barions fluctuate.

2) Adiabatic, when the ratio n_B/n_γ is maintained constant, that is, barions and photons fluctuate. These fluctuations are subject to strong damping[22] so that no fluctuations envolving masses smaller than $M_D \sim 10^{12} M_\odot$ for $\Omega_p = 1$ or $M_D \sim 10^{14} M_\odot$ $\Omega_p = 0.1$ can survive[23].

Although in general fluctuations contain both patterns we quoted above, the following scenario derives respectively from them:

1) Hierarchical, where the small structures are formed first and the larger ones are built up by gravitational interaction. In this picture, for example, the rotational velocity of galaxies is due to tidal forces among neighbouring galaxies, which consequently have opposite angular velocities and the covariant function for galaxy distribution does not present any characteristic mass scale[24].

2) Fragmentary, where due to dissipation the larger structures come up first, and the smaller ones are attained by fragmentation due to shock waves that would cause the structures to rotate. In this kind of model the covariant function must show some characteristic mass scale of order M_D, holes and strings of matter can be explained[25].

It is considered a strong argument in favor of the adiabatic fluctuations the fact that proposed mechanisms to generate barionic number within the frame of GUTs freezes out the quantity $r \equiv n_B/n_\gamma$ being consistent only with adiabatic fluctuations[26], fact which has been considerably well explored[27][28][29].

A proposition on the formation of structures in the Universe

The use of elementary particles spectrum to generate primordial density fluctuations and solve galactic dynamics problems is almost a sort of tradition. The list of examples is very wide and includes massive neutrinos[30], gravitinos[31][32], photinos[33], axions[34] and topological objects as strings[35] and also domain walls[36] in spite of dramatic estimations as (23). Following these steps we propose that the remnant of the walls that emerged from the alternative conception to the study of phase transition should work as structure seeds. The following conditions must be fullfiled for the proportion to be consistent:

1) The structures that act as seeds should not dissipate until recombination. This is possible if we keep in mind that:

a) topological conservation laws assure the non-dissipation of structures such as walls (solitons);

b) although the behaviour of walls becomes unknown below T_c within the equilibrium thermodynamical approach, it is believed that the walls would close as "bubbles" with a diminishing radius until zero temperature when the system reaches a unique phase. A rough representation of the real situation would be that given by figure (1).

2) The presence of walls should not alter significantly Hubble expansive flux. This can be demonstrated if we suppose that the "bubbles" are uniformly distributed and integrating Friedman's cosmologic dynamic equation in the presence of solitons, that is:

$$\dot{R}^2(t) + k = \frac{8\pi G}{3} (\rho_{particles} + \rho_{walls}) R^2(t) \quad . \qquad (37)$$

The relation between R(t) and T is obtained from the covariant conservation of the matter and radiation energy-momentum tensor and from this it resulted that RT is constant[17]. This relation is a very good approximation when solitons are present because their contribution is subdominant. In order to see this one has to extend expressions (20) and (22) to GUTS and to the Weinberg-Salam model. Explicit calculations in Gauge theories[37] indicates that, roughly speaking, the extension of these expressions to Gauge theories are given by

$$\rho(T) = \frac{\pi^2}{30}\, n(T)T^4 + n(T)\,\frac{\mu^2}{2\alpha}\,(T^2 - T_c^2) \tag{38}$$

$$p(T) = \frac{\pi^2}{90}\, n(T)T^4 + n(T)\,\frac{3g}{32}\,(T^2 - T_c^2)^2 \tag{39}$$

where μ is the "wrong mass" term in the Higgs potential $n(T)$ is the effective number of degrees of freedom at the temperature T. For a GUT such as SU(5) $n_{GUT} \sim 160$ whereas for the Weinberg-Salam model $n_{WS} \sim 97$. (One just recall that one has to introduce a convenient spin degrees of freedom factor counting[17]). In order to see how the presence of domain walls affects the evolution of the Universe we make the approximations, $\alpha = 1$ [15] and

$$n(T)\, g \sim 1 \quad . \tag{40}$$

The hypothesis (40) is perfectly compatible with the semiclassical approximation. From the explicit integrations one gets

$$t = \begin{pmatrix} 2,3 \\ 3,0 \end{pmatrix} \cdot 10^{-2}\, \frac{M_p}{T^2} + \begin{pmatrix} 3,7 \\ 7,9 \end{pmatrix} \times 10^{-6} \left[\frac{M_p}{T^2} + \frac{2M_p T_c^2}{T^4} - \frac{4}{3} M_p \frac{T_c^4}{T^6} \right] + \dots \tag{41}$$

where M_p is the Planck mass ($M_p = G^{-1/2}$) and the upper numbers in brackets in (41) represent the result for minimal SU(5) whereas the lower numbers represents the contribution of the Weinberg-Salam model. Thus one can see that the presence of domain walls just represents a subdominant contribution to that predicted by the standard Friedman model (the first term in the right hand side of (41)).

3) It becomes necessary to satisfy Zel'dovich's (36) condition for the proposed scenario:

$$\frac{\delta\rho}{\rho} \equiv \frac{\rho_{wall}}{\rho_{total}} \cong \frac{\rho_{wall}}{\rho_{particles}} = \begin{cases} 9 \,.\, 10^{-4} \text{ GUTS} \\ \\ 1.6 \; 10^{-3} \text{ W.S.} \end{cases} \qquad (42)$$

which is consistent with (36). This ratio has been computed for $T = 2T_c$.

4) The length of fluctuation must be greater than Jeans length, so as to enable it to trigger the gravitational mode (29) when recombination occurs.

The length of fluctuation that is proposed here is essentially the distance between two walls and it is given by (32) when is close to T_c . This dimension can be evaluated supposing that the remnants of the walls below T_c , expand conformally[10] keeping the ratio between the distance between solitons and the horizon distance constant and so during recombination:

$$L^{GUT} = \frac{d_0^{GUT}}{d_H(0,2.10^{-37}seg)} \times d_H(0,t_R) = \frac{10^{-28}\,cm}{2.2\;10^{-37}seg} \times 2\;10^5 \text{ years} \cong$$

$$\cong \; 1.4 \; 10^{21} \text{ cm} \qquad (43)$$

that is larger than (34). So the fluctuations generated by the objects produced during the GUT phase transition obey all necessary conditions to the formation of structures in the Universe. The corresponding mass to (43) is:

$$M^{GUT} = \frac{4\pi}{3}\,\rho_{rec}\,L^3_{GUT} \sim 10^{10}\,M_\odot\,\Omega_p \qquad (44)$$

which fits very well in the galactical mass spectrum and is probably consistent with all of them if the dynamics of the "bubbles" below T_c is considered.

If the same path is followed for the Weinberg-Salam phase transition, it is possible to show that the generated fluctuations are non-relevant because $L^{W.S.} << \lambda_J$. As the walls do not change the photonic bath, the proposed fluctuations are isothermal and so consistent with the hierarchical scenario. A legitimate conclusion would be that the number of aglutination centers is roughly the number of great structures observed in the Universe today. In fact, one can estimate the number of aglutination centers. This number is roughly given by

$$n_{\text{aglu center}} \cong \left(\frac{d_H(0,t^{GUT})}{d_0^{GUT}}\right)^3 \cong 1.9 \times 10^6 \quad . \tag{45}$$

The greater known structures are the superclusters of galaxies that consist of groups with an average of 10^5 galaxies, that have densities close to critical $\rho_c \sim 10^{-29}\ gcm^{-3}$ and spread over dimensions from 50 to 100 Mpcs (from 1.5 to 3.0×10^{26} cm). The number of these structures (sub-clusters) may be estimated by the ratio

$$n_{sc} = \left(\frac{d_H(0,t_p)}{d_{sc}}\right)^3 \cong 7.10^5 - 6.10^6 \tag{46}$$

because $t_p \sim 10^{10}$ years and $d_H(0,t_p) = 3t_p \cong 2.7 \times 10^{18}$ cm.

The results from (46) and (45) are quite close to each other. If it is taken into account that superclusters have peculiar speeds of 100 km/s, we may conclude that during Hubble's period these structures must have moved just some

Mpcs and that their distribution is therefore cosmological making thus the above coincidence very interesting.

CONCLUSIONS

We sketched in this paper an alternative picture of cosmological phase transitions. It differs from the orthodox one in many respects. This new picture is based on the idea that symmetry restauration will take place as a result of condensation of topologically non trivial field configuration being thus very close to the Kosterlitz-Thouless picture of phase transitions.

We have also studied some cosmological implications of the alternative picture such as the cosmological constant, the domain wall problem, the density contrast associated to a condensate of walls and its role in Galaxy formation. Our picture leads to a natural solution of the wall problem in cosmology as well as to a small value to the cosmological constant.

The most impressive results however, from the point of view of cosmology, are concerned with the formation of structures of the Universe. Up to now much effort has been made in obtaining Zeldovich's contrast density. We have shown that domain walls provide the density contrast of the required order of magnitude for Grand Unified Theories and the Weinberg-Salam Model. If one imposes further that the length of fluctuations do exceeds Jeans' length then only the fluctuations generated by GUT phase transition satisfies this requirement. We have shown that fluctuations originated from

GUT phase transition obey all necessary conditions to the formation of structures in the Universe. Furthermore a rough estimate of the number of aglutination centers is equal to the number of great structures observed in the Universe today. The fact that the distribution of superclusters is cosmological makes this coincidence even more interesting.

The proposed scenario is of course unable to cope with a wide variety of important difficulties concerning the Standard Big-Bang model and it has the disadvantage of being consistent with isothermal density fluctuations. It is an interesting example of how some troubles in cosmology can be solved even without a more fundamental approach involving quantum gravity corrections in the Planck Era.

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FIGURE CAPTIONS

Fig. 1 - Picture of symmetry restoration and breakdown as a result of "defects" in the system.

Fig. 1-A - Picture of the system for $T > T_c$. Under these circunstances the system restores the symmetry as a result of a condensate of domain walls.

Fig. 1-B - Image of the system for $T < T_c$.

Fig. 1-C - Image of the system for $T << T_c$.

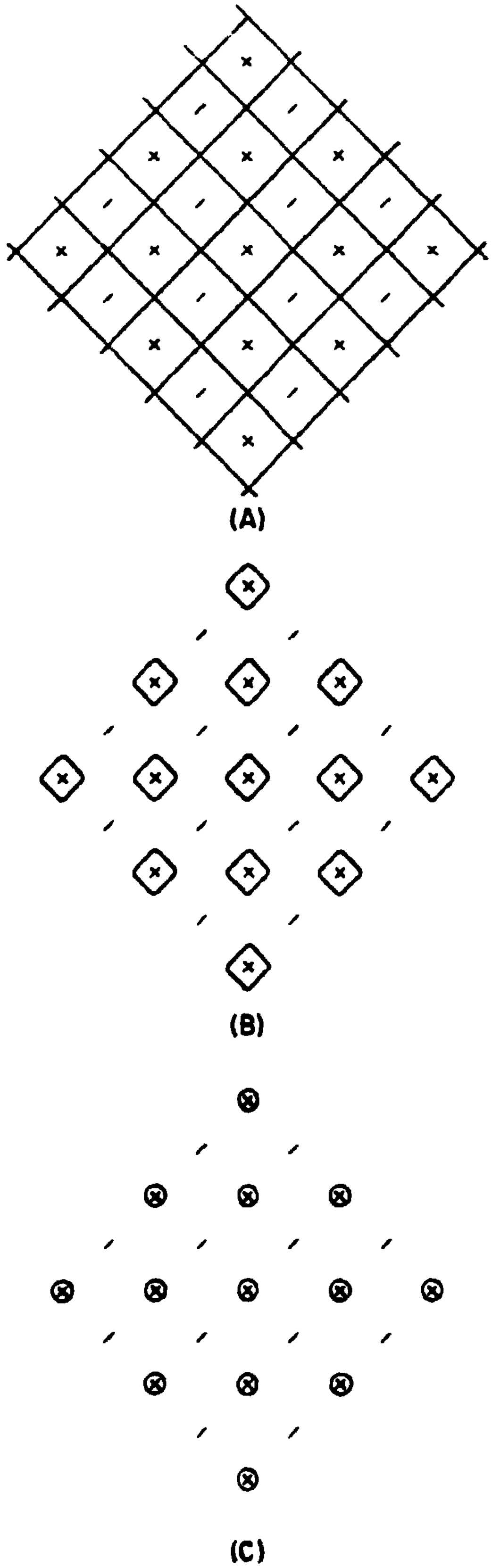

Fig. 1