The growth of the Universe. Another explanation for redshift.

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Abstract

At present, the idea that our space-time is emergent, as a kind of low-energy phase transition into some kind of condensed matter and superconductor, is becoming quite popular. This space-time is formed as a kind of new network, the volume of which, when measured in Planck units, is equal to the number of network nodes. The growth of such a network and the increase in its volume is not due to the stretching of existing cells, but as a result of adding new cells. Considering the growth of such a network in a similar way to the growth of the volume of a new phase, one can naturally explain the redshift and many other problems of modern cosmology.

1 Introduction

First, we noticed that already within the framework of standard GR, taking into account the structure of vacuum in the form of a certain crystalline medium can lead to an inflationary scenario and give rise to dark energy and dark matter effects [1]. It was a good try in this direction. However, further work in this direction showed that the consideration of our vacuum as some kind of condensed matter has a deeper foundation than it seemed to us at the beginning, and gives serious impetus to attempts to take a fresh look at our emergent space-time and many physical processes [2–20].

The theory of the Higgs boson with a mass of about 125 GeV and the associated Higgs field, which plays a fundamental role in particle physics, was inspired by ideas from condensed matter physics. This ideas originally had been offered by Philip Anderson [21, 22]. He discussed spontaneous symmetry breaking (SSB) in superconducting condensates and considered it as a general “mechanism” for the processes of emergence and mass generation. Many physicists have urged that the name of this process should be changed to the “Anderson-Higgs” mechanism [23]. Moreover, the ideas of SSB and emergence have become dominant in many classic papers on theoretical physics.

Kenneth Wilson considered our space in the form of a superconductor, the structure of which was represented by a kind of graph. Thus the space was imagined as a lattice made of nodes connected by edges [2, 5, 6].

This direction, that our emergent spacetime and vacuum are a kind of condensed matter and a superconductor that appear as a phase transition and elementary particles appear as excitations and SSB of this condensate, gets serious development and has become very popular.

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«The similarities between the vacuum of space and low-temperature phases of matter are legendary in physics.» - Robert Laughlin [3].

Assuming that physics should be discrete on the Planck scale, the models for the formation of such space-time networks (spin network, causal set, ...) were considered as composed of discrete, indivisible spacetime atoms. Such space-time grows by the accretion of new spacetime atoms [2,24–28].

In light of this approach, it has also become a topic of great interest in recent cosmology, considering the emergent scenario of cosmic evolution. Particular interest in this was fueled by the fact that it describes a non-singular origin of the Universe unlike the Big-Bang models [29–34]. Such cosmic evolution scenarios based on non-equilibrium thermodynamics and phase transitions are also becoming increasingly popular.

2 Model of the emergence and growth of the Universe

Let’s continue moving in this direction. Lee Smolin [2]: "The big bang is then not the origin of all that exists, but only a kind of phase transition by which a new region of space and time was created, in a phase different than the one from which it came". Dynamics the growth of such a new region of space and time resulting from a phase transition is determined by the accretion of new spacetime atoms. In principle, these emergent space-time ideas are well known and actively developed, as noted in the introduction. The only new thing I want to suggest for thinking about is to try to consider the “incredible”.

Let us consider the mechanism of accretion of new spacetime atoms not in the spirit of the now popular mathematical model ‘transitive percolation’ proposed by Rideout and Sorkin [26], but in the spirit of the growth of new phases commonly observed in nature. Thus, the growth of the structure and the attachment of new cells to it occurs at the boundary of the formed new phase.

Such an emergent space-time like a condensed network, which has the properties of a superconductor, can be represented, as noted by Kenneth Wilson [5,6], by a kind of graph and as a lattice made of nodes (spacetime atoms) connected by edges. Accordingly, we can consider the growth and increase in the size of such a superconductor lattice formed as a result of a phase transition, and the effects arising from this.

3 Redshift

Accordingly to Quantum Fields on a Lattice [35], we consider a discretized space-time lattice which extends over \( l = l_1 = l_2 = l_3 \) in every spatial direction and length \( l_4 = t \) in the temporal direction (\( \hbar = 1 \)).

\[
\Lambda = \{ x = (x, x_4) \in d\mathbb{Z}^4 \mid 0 \leq x_\mu \leq d(l_\mu - 1) \},
\]

where \( d \) - is lattice spacing.

The propagation of waves on such a lattice as well as for a scalar field must be subject to periodic boundary conditions in the form:

\[
\phi(x + d\hat{\mu}l_\mu) = \phi(x)
\]

where \( \hat{\mu} \) is the unit vector in the \( \mu \)-direction.

The Fourier transform of a function \( f(x) \) is defined by
\[ \tilde{f}(x) \equiv \sum_x d^4 e^{-ipx} f(x) \]

that should be periodic in momentum-space.

The allowed lattice momenta are given by

\[ p_\mu = \frac{2\pi}{dl_\mu} n_\mu, n_\mu = 0, 1, \ldots, l_\mu - 1. \]

The wavelength propagating in the lattice space will be

\[ \lambda_i = \frac{L_i}{n_i}, \quad \text{(1)} \]

where \( L_i = dl_i \) is the lattice spatial size (\( i=1,2,3 \)).

It should be taken into account that the formula (1) is valid only for weak fields and long-wavelength oscillations that satisfy the superposition principle.

Consequently, the spectrum of waves in the lattice will change depending on its size.

**Note:** This is a well-known effect. If, for example, a vibrating string on a guitar, which is a one-dimensional chain of interconnected atoms, is clamped in different places, then the sound it emits will also change.

Let us take a simplified case of an isotropic spherical lattice. Then the propagation of waves in any direction can be considered as vibrations of a one-dimensional chain of atoms along the diameter of this ball, which coincides with the direction of these waves.

From the above formulas, it is easy to see if the radius of such a lattice will change \( R(t) = a(t)R_0 \), then the length of the wave traveling in it will also automatically change. Denote \( t_0 \) – observation time and \( t_1 \) – wave emission time (\( t_0 > t_1 \)). Respectively, \( \lambda_0 \) – observed wavelength, \( \lambda_1 \) – emitted wave, \( a_0 \) – scale factor \( a(t_0), a_1 = a(t_1) \). Then the spectral shift will be

\[ Z_c = \frac{\lambda_0 - \lambda_1}{\lambda_1} = \frac{a_0}{a_1} - 1. \]

We can expand \( a(t) \) into a series \( a(t_1) = a(t_0)[1 + (t_1 - t_0)H_0 + \ldots] \), where \( H_0 \) is a constant related to the rate of change in the lattice size. In a linear approximation the resulting redshift can be expressed in terms of the time difference between emission and absorption or in terms of the distance between the emission and absorption places \( l = c(t_0 - t_1) \), where \( c \) - wave propagation speed.

\[ Z_c \approx (t_0 - t_1)H_0, \quad \text{(2)} \]

\[ cZ_c \approx lH_0, \quad \text{(3)} \]

Thus, if we consider our emergent space-time as a kind of phase transition by which a new region of space-time was created and grows similarly to the usual growth of a new phase and the growth of a crystal, then we will get the same formulas for the redshift as in standard cosmology. Only the mechanism of such expansion of the Universe "slightly" differs from those accepted in general relativity. Instead of Big-Bang and inflation, there will be a new phase nucleation and growth by adding new elements to it.
Note: If the shape of the emergent space of our Universe is not spherical and $L_i \neq L_j$, then, as it can be seen from (1), this should lead to anisotropy and a difference in the spectra observed in these directions. Although the redshift itself, if the growth of space occurs proportionally in all directions, will remain isotropic.

Such a new lattice structure of condensed matter (we can call it a world crystal), growing as a result of a phase transition that forms the growing space-time of our Universe, will be similar to the quantum vacuum in quantum field theory. And the observed matter, the particles of which are born from this vacuum as excitations leading to spontaneous symmetry breaking, will be similar to the defects of this world crystal.

Herewith, the growing world crystal (spin-network, quantum vacuum, superconductor) of our Universe and the defects born in it (observed matter) will have a uniform density, which is generally typical for crystals.

4 Conclusions

Of course, to obtain the desired results, one can introduce additional parameters based on abstract mathematical models such as anti-gravity or n-dimensional anti-de Sitter space ($AdS_n$). And these models may even come true in nature. But I think it still makes sense to look first for explanations similar to what we really observe in nature.

Let me remind the well-known statement of Robert Laughlin [3]: "There are legends in physics about the similarity between the cosmic vacuum and the low-temperature phases of matter."

And by simply following this popular trend that our emergent space-time has the properties of condensed matter and arises and grows as a result of a phase transition, similar to the growth of a crystal, we automatically come to explain the cosmological redshift and some other problems.

We note that such a model naturally solves some problems of cosmology:

1. It explains the redshift, which, as we have seen, will automatically appear in this case according to Hubble’s law.

2. It describes a non-singular origin of the Universe.

3. Vacuum density and density of elementary particles.
The vacuum of our emergent space-time is a kind of condensed matter and superconductor. The elementary particles born in it appear in the form of excitations and SSB of this condensate. These particles form observable (and dark) matter.

It is obvious that the vacuum density and the density of elementary particles born in it are two completely different things.

4. It very naturally removes the worst problem of the cosmological constant $\Lambda$, which was associated with the cosmological vacuum energy density and the expansion rate of the Universe [2, 36]. In our model, the expansion (growth) of the Universe is explained by the standard mechanisms of phase transitions. The density of the vacuum lattice (the world crystal) may well correspond to those huge values predicted by quantum field theory, and this absolutely does not prevent us from obtaining the growth rate of
the Universe in accordance with the observed data.

5. **It proposes a natural candidate for the role of dark energy.**
The growth rate of a crystal or a new phase strongly depends on the properties of the external medium and the interaction with it. In our model, the environment external to our Universe will be naturally dark for us and will play the role of dark energy, which affects the expansion of our space-time.

6. **Multiverse.**
Our model also leads to the increasingly popular idea of the Multiverse [37, 38]. Since the space-time of our Universe arises and grows as a result of a certain phase transition, an external environment must exist outside our Universe. It is obvious that, under these conditions of the phase transition, other nuclei (other Universes) of the new phase can also arise and grow in this external medium. In our model, however, they will have a similar structure and properties.

7. **The consequences of this model are in many respects similar to the results in standard cosmology.**
It should also be noted that the cosmological scenario resulting from such a model is in many respects similar to the established inflationary scenarios and Hot Big Bang theories in general relativity. The redshift in this model is also explained by the expansion (growth) of the Universe. Since the space-time of our Universe is considered as a kind of spin-network (multilayered superconductor, crystal lattice), this network has some binding energy. At high temperatures above this binding energy, this network (our space-time) will melt and cannot exist. Our space-time network emerges only at a temperature below the critical as a low-temperature phase transition. As Lee Smolin [2] describes it: “... what is usually called the big bang is, in fundamental terms, the big freeze. What caused our world to exist was probably not so much an explosion as an event that caused a region of the Universe to cool drastically and freeze.” Thus, in this model, our Universe also goes through a transition from hot to cool drastically and freeze, with all the known consequences that follow from this.

Thus it turns out, if we follow the ideas expressed here, then today’s cosmology, built on general relativity, can be preserved in many aspects, but in many respects fundamentally reworked.

5 **Appendix**

A. **New phase growth rate**
As already noted, there are many models for the growth of a new phase that try to take into account the properties of the medium and the conditions under which the phase transition occurs.

According to the rather widespread Wilson–Frenkel model of the phase transition kinetics of liquid freezing, the growth rate of a new solid phase \( V \) under the condition of low overcooling \( \Delta T \) is determined by the formula [39]:

\[
V = A \nu \exp\left(-\frac{E}{kT}\right) \exp\left(-\frac{\Delta S}{k}\right) \{1 - \exp\left[-\frac{\Delta H}{k} \left(\frac{1}{T} - \frac{1}{T_0}\right)\right]\} \simeq \beta^T \Delta T, \tag{4}
\]
\[ \beta^T \simeq A \nu \frac{\Delta S}{kT} \exp\left(-\frac{\Delta S}{k}\right) \exp\left(-\frac{E}{kT}\right) \]

\( \beta^T \) is called the kinetic coefficient of crystallization, \( A \) is a constant that depends on the properties of the crystal, \( \nu \) is the frequency of thermal vibrations of atoms in a crystal and in a liquid (both frequencies are assumed to be equal). To change the configuration, atoms have to overcome the energy barrier \( E \), and this probability is expressed by \( \exp\left(-\frac{E}{kT}\right) \) at a temperature \( T \). The entropy difference between the liquid and solid phases \( \Delta S = S_L - S_S \). The latent heat \( L \) generated at the melting point corresponds to the enthalpy difference between the liquid and solid phases as \( L = H_L - H_S = \Delta H \).

Let us emphasize the main conclusion from equation (4), which is also confirmed in other models: **The growth rate of the new phase will accelerate with increasing supercooling \( \Delta T \).**

Even in laboratories, it is impossible to create ideal crystals growth. Obviously, due to various stochastic processes, the magnitude of supercooling will also fluctuate, and with it the growth rate of the new phase.

Probably, it is precisely such fluctuations that we have in our observable Universe.

"The new finding suggests that the Universe has slowed down and speeded up, not just once, but 7 times in the last 13.8 billion years, on average emulating dark matter in the process" [40, 41].

On our Earth we also had already several phases of cooling and warming.

**B. Experiments to test the increase in distances between galaxies**

Time dilation [the stretching of time by a factor of \((1+z)\)] is a fundamental property of an expanding Universe. However, as stated in the study [42], over 800 quasars on timescales from 50 d to 28 yr are monitored: “**The results ... provide strong evidence that the effects of time dilation are not seen in quasar light curves.** This clearly runs against expectations based on a conventional cosmological viewpoint, and so in this section we examine ways in which the results may be understood. ... it turns out to be surprisingly hard to formulate a conclusive test for time dilation.”

In a study by Foley et al. (2005 [43]) on supernova light curves, it was evaluated as confirmation of the time dilation. However, these conclusions has been challenged in the Crawford’s paper (2009 [44]).

Other different indirect tests are also mentioned to verify whether the Universe is expanding or static [45]. However, these experiments also did not provide convincing evidence that the distance between galaxies is increasing. “Nobody has ever directly observed a galaxy distance being increased with time. The motion of the putative expansion of the Universe is so slow that it is unmeasurable.”

**C. Vacuum density and space-time curvature**

In quantum field theory and in QCD, elementary particles and antiparticles are considered as perturbations and holes in our vacuum. The density of this vacuum is simply enormous. An additional argument to the theoretical calculations of the high vacuum density can be the claim that it should be sufficient for its perturbations to lead to the...
creation of the observed heavy elementary particles. Thus, it must be many orders of magnitude higher than the discussed vacuum in cosmology. If such a vacuum energy density is substituted into Einstein’s equations, then we should get the colossal curvature of space-time, although in reality it is about zero.

There will be no contradiction in this if we look at Einstein’s GR equations from the other side

\[ R_{\mu\nu} - g_{\mu\nu}R/2 + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}. \]

They describe how observable and dark matter distorts already existing space-time.

The vacuum of our emergent space-time is a kind of condensed matter and superconductor. Elementary particles born in it form observable (and dark) matter. It is obvious that the vacuum density and the density of elementary particles born in it are two completely different things.

Our emergent space-time, arising as a result of a phase transition, will be deformed and distorted under the influence of elementary particles born in it, just as condensed matter is deformed by defects arising in it. In the absence of defects (particles born in vacuum), our vacuum remains undeformed. At a low density of this elementary particles, the deformation and curvature of the space-time will also be extremely small.

Gravity does not create our emergent space-time. Gravity only deforms it (stretches, compresses, bends), already existing.

D. Vacuum density and space-time expansion.

1. Unfortunately, modern cosmology does not take into account at all that the vacuum density of our emergent space-time and the density of particles born in it are absolutely different things. The very weak anti-gravity described in cosmology and, accordingly, the microscopic anti-pressure, which is capable of dispersing cosmic dust (an extremely low density of elementary particles that were born in this vacuum), are naturally unable to expand the superdense emergent space-time vacuum and break the huge forces that bind it. This is equivalent to a light breeze and micro-pressure trying to inflate a diamond crystal.

2. If we assume that the cosmological forces of antigravity are so powerful that they are able to expand even this emergent space-time with its superdense vacuum, then in this case all other bodies observed in our Universe will undergo the same expansion. This would only lead to a proportional stretching of all scales and standards, and all distances and wavelengths in the new standards would remain the same.

References


[40] H.I. Ringermacher, L.R. Mead, "Reaffirmation of cosmological oscillations in the scale factor from the Pantheon compilation of 1048 Type Ia supernova", MNRAS 494, 2158–2165 (2020).


