A Different Cosmology - Summary

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Abstract—This paper summarizes a new model of cosmology based on the idea of a universe with time-varying curvature dominated by vacuum energy acting as its own source. In this model, the universe began with an exponential Plank era inflation before transitioning to a spacetime described by Einstein's equations. While no explicit model of the Plank era is yet known, a number of properties are established that the vacuum of that era must have exhibited. In particular, it is shown that structures came into existence during that inflation that were later responsible for all cosmic structures. A new solution of Einstein's equations incorporating time-varying curvature is presented which predicts that the scaling was initially power law with a parameter of gamma = 0.5 before transitioning to a present-day scaling that is undergoing an exponential acceleration. A formula relating the curvature to the vacuum energy density is appears as part of the solution. A non-conventional model of nucleosynthesis provides a solution of the matter/antimatter asymmetry problem and a non-standard origin of the CMB. The CMB power spectrum is shown to be a consequence of the same large structures and of uncertainties also embedded in the vacuum during the initial inflation. Using Einstein's equations, it is also shown that so-called dark matter is, in fact, vacuum energy.

Keywords—Evolution of the Universe – Inflation – Big Bang nucleosynthesis – Cosmic microwave background – Dark matter – Dark energy

I. Introduction

In this paper, we summarize a new model of cosmology that was developed in a recent paper, [1]. This model represents a significant departure from the standard model and makes a significant number of predictions that agree with observations without any parameter adjusting or curve fitting being involved. The details of the model are described in the paper and we won't repeat any of the calculations here. Instead, we will focus on the results with emphasis on the global aspects of the model rather than on particular details.

The principal idea that emerges from this work is that the spacetime vacuum is not featureless as is generally assumed. Instead, it has structure that was responsible for all the cosmic structures we see. We can state this succinctly in terms of the energy-momentum tensor. Instead of the standard model concept of the vacuum given by

$$\mathbf{T}^{\mu\nu} = 0, \tag{1}$$

in this new model, the vacuum acts as its own source so that we have

$$\mathbf{T}^{\mu\nu} = (\rho c^2(ct,r) + p(ct,r))\delta_0^\mu \delta_0^\nu + p(ct,r)\mathbf{g}^{\mu\nu} \tag{2}$$

We also determined that, instead of being constant, the curvature of spacetime must vary with time. A solution of the resulting Einstein's equations shows that the scaling must have the form,

$$a[ct] = a_* \left(\frac{ct}{ct_0}\right)^{\gamma_*} e^{\frac{ct}{ct_0}c_1}. \tag{3}$$

where

$$\gamma_* = \gamma_h + \bar{k}_0 \frac{(1-\gamma_h)^2}{\gamma_h} \tag{4a}$$

$$a_* = a_0\, e^{-c_1} \tag{4b}$$

The parameters have the values $\gamma_h = 1/3$, $\gamma_* = 0.5$, $\bar{k}_0 = 1/8$, and $c_1 = 0.45$. We see that the scaling is power law for $ct/ct_0 \ll 1$ and exponential for $ct/ct_0 \geq 1$. The curvature is given by

$$k[ct] = \bar{k}_0 \left(\frac{a[ct]}{ct}\right)^2 \tag{5}$$

which is related to the vacuum energy density and pressure by

$$k[ct] = \frac{1}{2}\gamma_h\, a[ct]^2 \kappa\, (\rho c^2[ct,0] + p[ct,0]). \tag{6}$$

The sum is thus a fixed function of time,

$$\rho c^2[ct,0] + p[ct,0] = \frac{2\bar{k}_0}{\kappa (ct_0)^2 \gamma_h} \frac{(ct_0)^2}{(ct)^2}. \tag{7}$$

Later, it will be shown that all physical quantities, not just the curvature, are functions of this sum rather than either individually.

Everything is now fixed and unambiguous predictions can be made. Note also that there is no direct relationship between the scaling and the energy density or pressure so that the present-day acceleration of the scaling follows directly from the time variation of the curvature and has nothing to do with a cosmological constant or, in other words, so-called dark energy.

This situation is completely different from that of the standard model because the latter does not, in fact, actually predict anything purely on the basis of being a solution of Einstein's equations. By making choices about various parameters, it is possible to predict any sort of evolution of the universe one cares to see. In the new model that is not the case. There is one solution, there are no free parameters, and *only one evolution is possible*.

In this model, the universe began with a Plank era inflation that lasted until that age of the universe became large compared to the Plank time, $t_P = 5.39x10^{-44}s$. Following the inflation, there was a transition period lasting for about 1500 Plank times after which the solution quoted above determined the subsequent evolution.

The process described so far would only account for an empty universe so we need to extend these ideas to account for ordinary matter and the observed cosmic structures. What

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we are going to argue is that all cosmic structures owe their origin to vacuum structures that originated during the Plank era. To see how this came about, we need to start with the Plank era and work our way forward toward the present day.

II. Plank Era

The Plank era was characterized by uncertainties and at the present time, we not only don't have a solid theory, we don't even have a workable framework to describe the era. Nevertheless, we will be able to say quite a bit about the properties of the vacuum that come into existence during that era. Imagine for a moment that you wish measure the interval of time between a pair of events. To so, one need a clock with tick intervals that are small compared to the interval of interest. Now image moving backwards in time to the beginning. Eventually, we reach a point at which the tick intervals can no longer be reduced and our assertion is that the minimal interval is the Plank time. The consequence is that there is an uncertainty about when the universe began given by the Plank time. Similarly, there was an uncertainty about dimension given by the Plank length. Because there is an inverse relationship between the radius of curvature and the vacuum energy density, it follows that there is a maximum possible energy density because a minimum realizable length places a lower limit on the radius of curvature.

In the paper, we presented a simple model that predicts an exponential inflation that ended when the uncertainties because small relative to the age of the universe. We also show that the conditions of the vacuum at the end of the inflation are completely consistent with the present-day size and energy of the universe. A typical solution is shown in the following Figure 1, Here, α and τ are the logarithmic scaling and

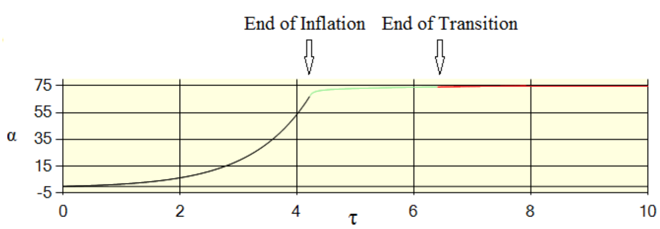

Fig. 1. Initial evolution of the universe.

time respectively. The evolution subsequent to the end of the transition is described by the solution of Einstein's equations given earlier and because the magnitude of the scaling at t_T is fixed by the solution and the present-day size of the universe, we see that a Plank era inflation must have occurred in order to get us from a Plank volume at $\tau = 0$ to the predicted volume at t_T. The radius of curvature is related to the curvature by $R_c(ct) = a(ct)/\sqrt{k(ct)}$ and since the radius of curvature by assumption was fixed at is minimal value, we find that the curvature must have increase exponentially during the inflation.

As we will see, the uncertainties that existed during the Plank era inflation were critical for the development of subsequent cosmic structure and this is particularly true for the largest structures. The reason for this is causality and as we will see, the largest structures are simply too big to have evolved at any time after t_T. This means that in some manner, their existence was established during the Plank era. During that era, we believe that some notion of causality existed but because of the uncertainties, concepts such as a speed of information transfer would be also be totally uncertain, i. e. $\Delta c \leftrightarrow \Delta l/\Delta t \to \infty$.

As has been pointed out by many people, Plank time, etc are just combinations of fundamental constants so given the fact of a Plank era, one has to wonder about the fantastic coincidence that a Plank era inflation based on those values matches up with the solution at t_T. A solution for this problem is that we are reading the Plank definitions the wrong way around. We should view the Plank dimensions as the fundamental constants and $c\,(= l_P/t_P)$, G, and $\hbar$ as derived quantities that are in some way properties of the curvature of spacetime. From this point of view, the derived constants are the values that came into being as the uncertainties became small relative to the age of the universe.

III. New Model of the Einstein Era

Moving on from the Plank era, by the end of the transition period, the uncertainties would have become negligible and normal causality would have come into play. The development of the new model begins with the idea that the universe consists of a sequence of hypersurfaces in which the vacuum energy is at rest. As in the case with the standard model, we make the assumption that these are homogeneous and isotropic with the consequence that there is no preferred origin and that all their properties are dependent only on time. We refer to this as the "real" universe to distinguish it from our perception of the universe. Our perception is concerned with signals, causality, and so on and these are dependent of both time and distance and are described by Einstein's equations. The question, then, is how to we reconcile the equations that describe our perception with a sequence of hypersurfaces that have no notion of an origin or distance? The answer is that Einstein's equations describe the universe as viewed by each observer from the viewpoint of an origin at the observer's location. But a hypersurface is simply the collection of all possible observer origins so Einstein's equations become the equations that describe the hypersurface when *evaluated at any observer's origin*.

Up to this point, there is some common ground with the standard model but from here on, things are different. In the standard model, the *assumption* is made that not only are the hypersurfaces homogeneous and isotropic, but the universe will appear homogeneous and isotropic. We established that the curvature must have varied with time during the Plank era and will make the critical assumption that it continued to vary afterwards and with time varying curvature the universe will *not* appear homogeneous although, as we will show, the observational differences are not large for moderate redshifts.

Putting these ideas together, the metric becomes,

$$ds^2 = (-1 + \frac{r^2 h(ct,r)^2}{a(ct)^2}(1 - k(ct)r^2))\,(cdt)^2 + 2h(ct,r)\,(cdt)\,rdr + a^2(ct)\,(\frac{dr^2}{(1-k(ct)\,r^2)} + r^2 d\Omega^2) \tag{8}$$

From here on, the development follows along the usual lines. After working out the Einstein's equations and taking the limit as $r \to 0$, the resulting equations can be solved in closed form. The solution was given in the Introduction. Aside from the present-day scaling and age of the universe, we need the value of the scaling at two different times to fix the parameters of the scaling. For one of these, we use a consensus value of the Hubble constant ($H_0 \approx 67.3$) and for the other, the present-day temperature of the CMB. (In order to understand the connection with the latter, some further development is needed which we will get to in a later section.) The remaining parameter is $\bar{k}_0$. Recall that during and shortly after the inflation, the curvature was maximal. This motivates an additional principle which states that the curvature must always be as large as possible or equivalently, that the vacuum energy density must always be as large as possible. From the solution, it then follows that $\bar{k}_0 = 1/8$ and $k_0 = 1.414$.

In Figure 2, we show the effective scaling parameter and the scaling as a function of time. The exponential acceleration of the scaling is clearly visible.

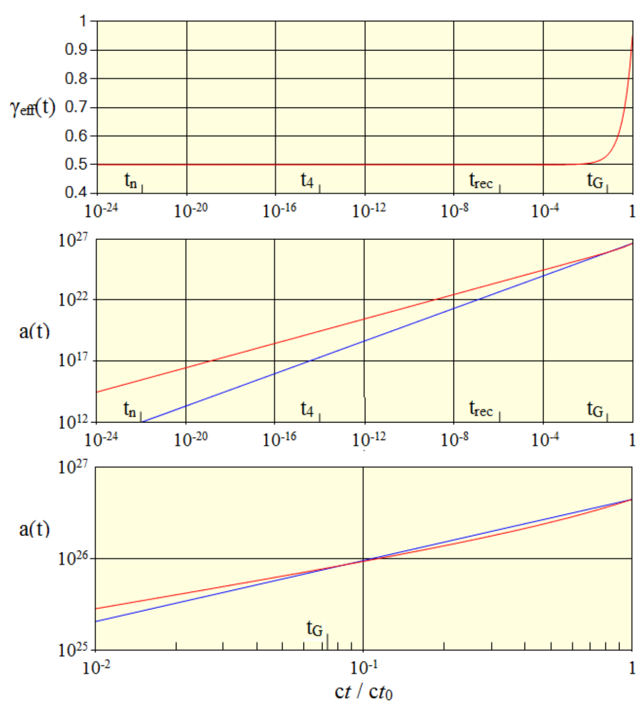

Fig. 2. Time-varying curvature predictions in red. For comparison, the curves for $2/3^{rds}$ scaling are shown in blue. The indicated times are: t_n = time of neutron formation to be explained below, t_4 = end of nucleosynthesis, t_{rec}= recombination, and t_G = galaxy formation.

The next result we show is a plot of the coordinate distance of sources whose signals are receive at the present time. The red curve is the time-varying curvature result. For comparison, we also show in black the result computed assuming a constant

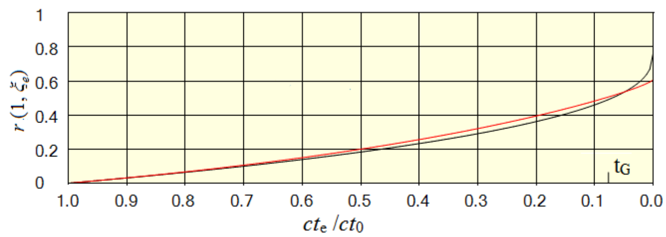

Fig. 3. $r(1,\xi_e)$ vs ξ_e.

value of $k = 1$. The two curves are similar for small values of look-back time but they differ considerably for large redshifts. In particular, with time-varying curvature, there is a fundamental limitation on our ability to detect distance sources. No matter how far back in time we look, we cannot see sources with coordinate distances greater than about $r = 0.6$. This is in direct contrast to the standard model in which no such limitation exists.

From (7), we find that the present-day vacuum energy density sum is

$$\rho c^2(ct_0, 0) + p(ct_0, 0) = 2.1x10^{-10} j\, m^{-3} \tag{9}$$

which we find differs from the value of the so-called dark energy density ($6.3x10^{-10} j\, m^{-3}$) by no more than a factor of 3. Note, however, that even though the magnitudes are similar, these are in no way equivalent and the notion of dark energy driving the acceleration of the scaling just does not exist in the new model.

We will conclude this section with the model prediction for the luminosity distance. Figure 4 shows the result.

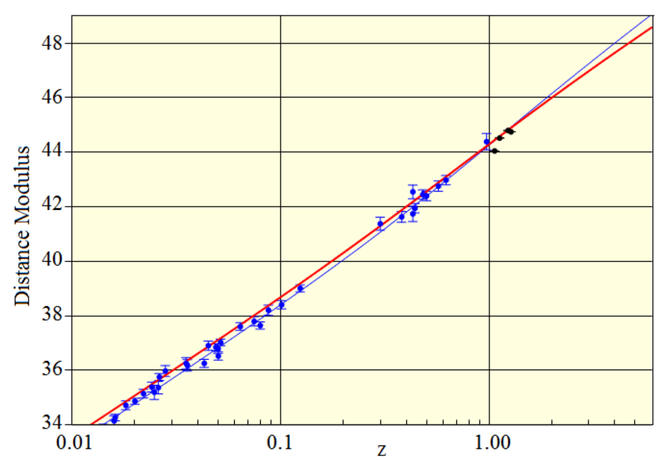

Fig. 4. Time-varying curvature prediction of the luminosity distance in red. The standard (0.24, 0.76) model is shown in blue.

We emphasize that this is a *prediction* rather than curve fit. (Using a slightly larger value for the Hubble constant gives an even better fit.) Given that the new model, which has no notion of a cosmological constant or dark energy, fits the data, we find that luminosity distance data does not provide any evidence for either. They only appear in the context of the standard model which we claim is wrong.

IV. Asymmetry, Radiation, and Nucleosynthesis

Initially, the only existence was the vacuum so the next step is to account for the creation of ordinary matter. The first step is to separate what is known from what is conjecture. Observations of the oldest galaxies allows the relative abundances of the light elements to be measured. Working backwards in time, the abundances at the end of nucleosynthesis can be estimated with some confidence because the processes that occurred during the intervening time period are known. Similarly, the nucleosynthesis reactions are also known so one can work backwards again to discover the relative abundances of the protons and neutrons that initiated the nucleosynthesis. We can also establish that the process began at a time of about $10^{-5}s$.

That, however, is a far as one can go. Whatever happened before a time of $10^{-5}s$ is beyond the reach of even extrapolations of observations. This means, for example, that there is no evidence to support the standard model's field theory beginning. Here, we will propose an alternate beginning that leads to the same nucleosynthesis starting point but which also can account for the matter/antimatter asymmetry of the universe.

At this point, we wish to establish the connection between the CMB and the scaling that we referred to earlier. The temperature of the CMB at the time of the initial particle creation is given by

$$T(t_n) = T(t_0)\frac{a_0}{a(t_n)} \tag{10}$$

and, assuming a black-body spectrum, the corresponding energy density was

$$\rho_\gamma c^2(t_n) = a_B T^4(t_n). \tag{11}$$

Clearly, the energy density at $t = t_n$ is fixed once the effective scaling is known. If we now assume a trial value of $\gamma_{eff}(t_{rec}) = 0.6$, say, we find that $t_n = 5.2x10^{-5}$ s and $\rho_\gamma c^2(t_n) = 6.9x10^{39} j\, m^{-3}$ but we also have $\rho_{vac}c^2(t_n) = 2.1x10^{34} j\, m^{-3}$ so we immediately see that the CMB energy density would be vastly larger than the total energy of the universe. If we turn the problem around and set the CMB energy density to equal the vacuum energy density, we find a value of $\gamma_{eff}(t_{rec})$ a little bit larger than 0.5. The actual value, however, must be less than that because the CMB does not contain all the energy. A value of ½ is a nice round number so from here on out, we will assume that $\gamma_{eff}(t_{rec}) = 0.5$ with the understanding that it may need a small adjustment in the future. The corresponding time is $t_n = 4.3x10^{-5}$ s.

This now fixes the scaling so we can determine the absolute initial abundances of the initial protons and neutrons by working backwards from the present-day abundances of ordinary matter. For the latter, the present-day average density of baryons is on the order of $n_{Ave}(t_0) = 1\, m^{-3}$. In the subregions where most of the nucleosynthesis took place, the density is 2-3 times larger and in the large voids, it is on the order of $n_{void}(t_0) = 0.016\, m^{-3}$. Starting with a value of $2\, m^{-3}$, we find a baryon density of $n_B(t_n) = 7.7x10^{33}\, m^{-3}$and a photon density of $n_P(t_n) = 1.5x10^{42}\, m^{-3}$. With these values, the radiation energy was about 0.1% of the vacuum energy density and that of the particles was vastly smaller even when their rest masses are included. Finally, the temperature $T(t_n) = 4.2x10^{11}K$ was about a factor of 10 smaller than the standard model value at that time. With these values, we have set the basic boundaries so the next step is to establish the sequence of events that lead to nucleosynthesis while at the same time accounting for the matter/antimatter asymmetry of the universe.

Since we start with a vacuum and we end up with both radiation and particles, there are three possible scenarios as shown in Figure 5.

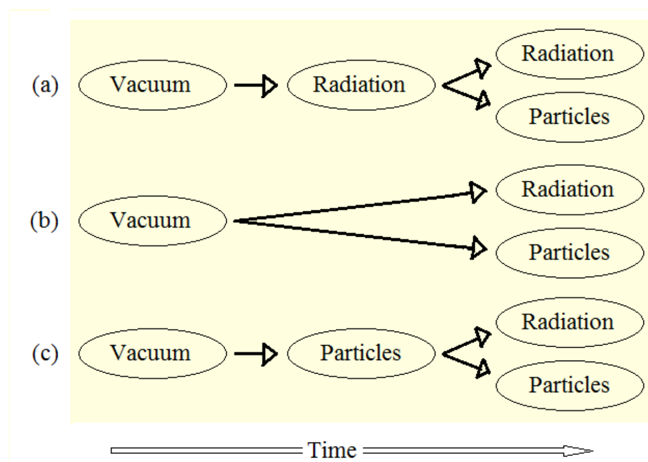

Fig. 5. Possible nucleosynthesis scenarios.

The standard model is an example of type (a). While such models can possibly account for the required proton/neutron densities for nucleosynthesis, they cannot account for the matter/antimatter asymmetry. The details are given in the paper. Another problem with the standard model is that is it just too complicated. Remember that all that complex interaction between radiation, quarks, etc, would have had to run to completion in $10^{-5}s$ everywhere in the universe *simultaneously*. At the same time, a signal could not have traveled even the diameter of a neutron until a time of $10^{-24}s$ and by t_n, communication was still limited to no more than $ct_n = 1.3x10^4m$ which we compare to $a(t_n) = 2.8x10^{15}m$.

Scenario (b) could account for the matter/antimatter asymmetry but it also suffers from being too complicated. The biggest problem, however, is that is doesn't provide a natural mechanism that would explain the required initial mix of protons and neutrons.

What remains is scenario (c). In this case, it is assumed that particles coalesced out of the vacuum without any accompanying radiation. We can also reasonably suppose that only a single type of particle was created with neutrons (and antineutrons) being the natural candidate. Suppose for the moment that only neutrons or antineutrons were created, but not both. The asymmetry problem is solved and possibly the

CMB could be explained as a result of kinetic energy of the neutrons being converted to photons via neutron β decay followed by $np \rightarrow \gamma d$. The fatal problem with this idea is that, in order to explain the CMB energy density, it requires the creation of too much matter by a factor of at least 10^8.

The alternative is that both neutrons and antineutrons were created in nearly equal numbers. The CMB can then be explained as the result of pair annihilation provided that the initial total density of particles was $n_m(t_n) = 1.6x10^{41}m^{-3}$.

The next problem is to explain both the matter/antimatter asymmetry and the final particle densities. As we noted earlier, the limitation imposed by the speed of light prevents any sort of communication over distances greater than about $10^4 m$. For convenience, we will denote such regions as "t_n" cells. Let us now imagine that locally some asymmetry in the creation process was introduced via random fluctuations. We can consider two limiting cases. First, let us assume that each entire cell was either matter or antimatter. The total number of such cells in the developing universe would have been about $N_{cell}(t_n) \approx 10^{32}$. Immediately after their creation, these cells would have begun to merge and annihilation would have begun. Eventually, the excess of one type of cell over the other would have been no greater than $\sqrt{N_{cells}} = 10^{16}m^{-3}$. Given the required initial density of particles, we would have ended up with a final particle density no greater that $10^{25}m^{-3}$ which is vastly smaller than the value of $10^{33}m^{-3}$ we calculated earlier.

The other limiting possibility is that neutrons and antineutrons were created randomly within each cell. This seems a lot easier to swallow but we end up with a similar result, namely that the final density of either neutrons or antineutrons could not have been greater that $\sqrt{10^{41}} = 3.2x10^{20}m^{-3}$within each cell and later merging of the cells would have reduced the number even further.

The conclusion is that no random process can explain the asymmetry so the asymmetry must have been the result of a biased random process. With a biased random walk, the number of neutrons and antineutrons created would have been $n_{total}(t_n)p$ and $n_{total}(t_n)p$ respectively. Solving for the probabilities and assuming a present-day density of $2\, m^{-3}$, we find

$$p = \frac{1}{2} + 2.4x10^{-8} \tag{12a}$$

$$q = \frac{1}{2} - 2.4x10^{-8} \tag{12b}$$

Thus, we find that a very small bias somehow embedded in the vacuum can explain the matter/antimatter asymmetry and further, there does not seem to be any other mechanism that could explain the bias. Also, this bias must have been the same, or nearly the same, everywhere which finally points us back the initial inflation because that was the only era during which normal causality did not hold.

With the origin of the CMB accounted for and a plausible explanation of the asymmetry given, we now need to account for the transition from all neutrons to a mix of neutrons and protons that will finally get us to the beginning of nucleosynthesis proper.

The answer to that problem lies in the following neutrino reactions.

$$\begin{aligned} n + e^+ &\rightleftharpoons p + \bar{\nu} \\ n + \nu \ \ &\rightleftharpoons p + e^- \\ \bar{n} + e^- &\rightleftharpoons \bar{p} + \nu \\ \bar{n} + \bar{\nu} \ \ &\rightleftharpoons \bar{p} + e^+ \end{aligned} \tag{13}$$

By assumption, we started with almost equal numbers of neutrons and antineutrons. Almost immediately, annihilation reactions would have begun and at the same time a few neutrons and antineutrons would have begun to decay. These, in turn, would have initiated a cascade of the reactions shown below in Figure 6 . A corresponding cascade beginning with

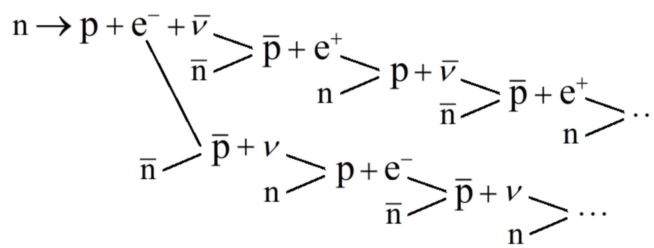

Fig. 6. Neutron-neutrino interaction cascade.

antineutrons would also have begun. These cascades would have continued until eventually enough protons and antiprotons were created to initiate the inverse cascades leading finally to an equilibrium ratio of

$$\frac{n_n}{n_p} = e^{-(m_n c^2 - m_p c^2)/kT} \tag{14}$$

From this point on, nucleosyntheses would have proceeded in the usual manner. The details concerning the equations and reactions are given in [1] and won't be repeated here. We will, however, show a few results because they have important implications later. First, we show in Figure 7 the results obtained when all the reactions listed in the paper are included. In Figure 8, we show the results obtained using the same conditions but with the reactions limited to those included in the standard model BBN simulation. Comparing we see that for the most part, the results are the same. The one exception are the final densities of Lithium. What is known as the Lithium problem is that the standard BBN model predicts a Lithium density 2-3 times greater that the observed value. The new model calculation yields a final density which is a factor of 2.8 smaller than the standard model value so we find that the so-called Lithium problem is simply a consequence of neglecting a number of known reactions from the reactions list. *The Lithium problem does not exist.*

We ran a number of cases to explore the dependence on the present-day particle density. The best match to the observed densities seems to be obtained in the range between $n_{part}(t_0) = 2 - 3\ m^{-3}$.

In the voids, the present-day particle densities are much smaller and in Figure 9, we show the predicted nucleosynthesis. We find that in the voids, protons make up essentially all the total with the relative density of ^4He about a factor of 10 smaller that in the high density regions.

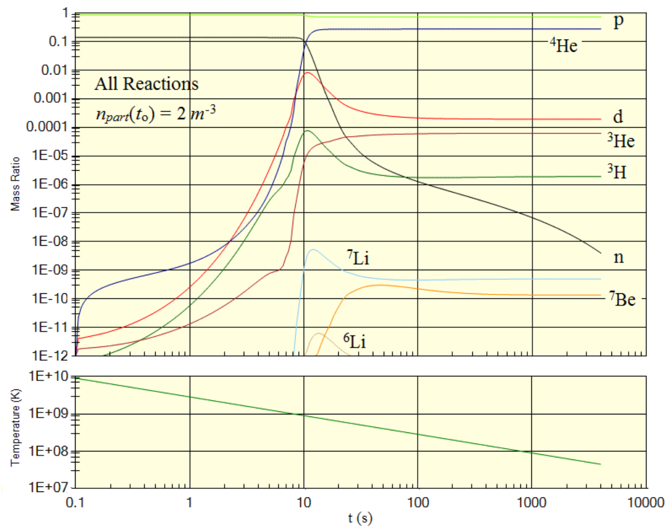

Fig. 7. Thermal nucleosynthesis, $n_{part}(t_0) = 2\,m^{-3}$ with all reactions included.

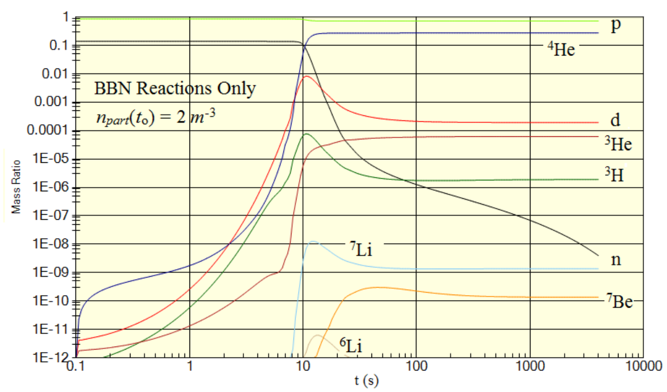

Fig. 8. Thermal nucleosynthesis, $n_{part}(t_0) = 2\,m^{-3}$ with only the BBN reactions included.

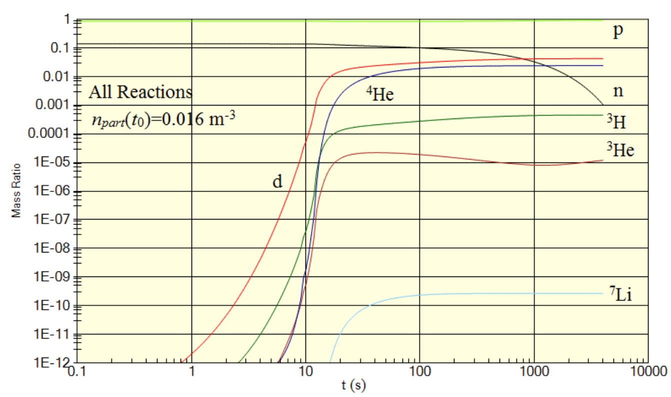

Fig. 9. Void thermal nucleosynthesis, $n_{part}(t_0) = 0.016\,m^{-3}$ with all reactions included.

V. Solution Revisited

Now that we have particles in existence, we will return to consider their interaction with the vacuum. Consider first the motion of a test particle with 4-velociy $u^\mu = (u^t, u^r, u^\theta, u^\varphi)$ for which the geodetic equations are

$$\frac{du^\mu}{d\tau} + \Gamma^\mu{}_{\nu\sigma} u^\nu u^\sigma = 0 \tag{15}$$

The important point is that the connection coefficients depend only on the metric components and these either have no dependence of the vacuum energy density and pressure or have a dependence only on the sum of the energy density and pressure. What this means, in turn, is that the motion of particles depends only on that sum. Thus, while we talk about the energy density and pressure as separate entities, only their sum has physical significance.

Next, we need to consider the effect of including the particles in energy-momentum tensor. With the particle density included, this becomes

$$\begin{aligned}\mathbf{T}^{\mu\nu} = (\rho_{vac}c^2(ct,r) + \rho_m c^2(ct,r) \\ + p(ct,r))\delta_0^\mu \delta_0^\nu + p(ct,r)\mathbf{g}^{\mu\nu}\end{aligned} \tag{16}$$

Ordinarily, after including a new term, we would set about solving the equations but, in fact, the equations haven't changed since the particle density just becomes part of the sum so the original solution still holds.

We are now in the position to refute the idea of accretion beginning with small particle density fluctuations being responsible for cosmic structures. The fact is that the sum of densities and pressure is fixed by (7) so any small variation in the particle density will be immediately cancelled by the corresponding variation in the vacuum needed to keep the sum equal to the RHS of (7) . Thus, structure formation initiated by small matter density fluctuations is impossible.

Nevertheless, to some degree accretion must have occurred but it would involve the sum of the vacuum energy density, pressure and particle density rather than any of those separately.

VI. Dark Matter

Dark matter was originally proposed to explain the motions of stars in galaxies and galaxies in galactic clusters that could not be understood solely on the basis of visible matter. Since then, it has become something of a catch-all to fix up the calculations whenever some cosmic phenomena cannot be otherwise explained. What we will now show is that dark matter is, in fact, vacuum energy. So-called dark matter has many manifestations and, in this section, we will consider the problem posed by the velocity distribution of stars in spiral galaxies and the velocity distribution of galaxies in galaxy clusters. The spiral galaxy problem is illustrated by the curves in Figure 10. Curve A is the velocity distribution of the stars calculated on the basis of the visible matter and curve B is the observed distribution. The generally accepted solution for this problem is to suppose there is a halo of dark *matter* surrounding the galaxy that provides the gravitation needed to match the observed velocity distribution. There are a number of problems with this proposal, however, not the least of which is the fact that a dark *matter* halo should act like a halo of stars with the lights turned off and hence the velocity distribution should match curve A instead of B.

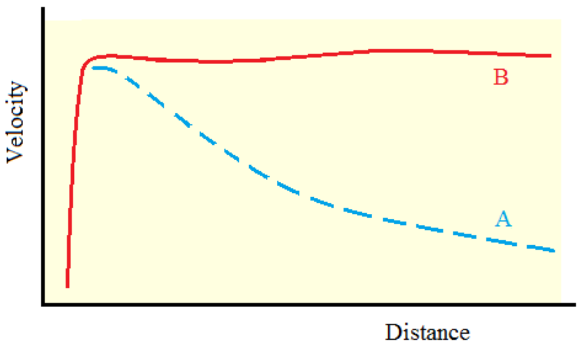

Fig. 10. Typical galactic velocity distribution.

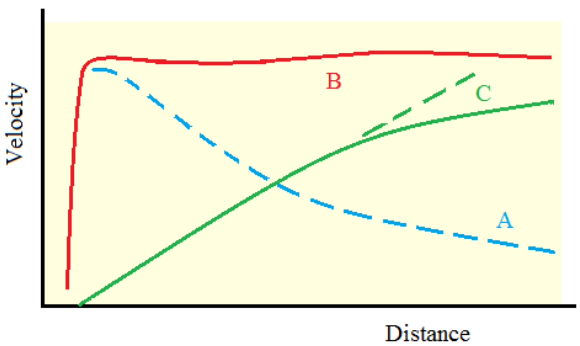

Fig. 11. Sum of gravitational and spacetime rotations..

A different solution is needed. We get a hint if we subtract the two curves to obtain curve C shown in Figure 11. This suggests that observed distribution can be understood in terms of normal gravitational interaction being carried along by a rotating spacetime.

There are two issues to be addressed; namely to explain first the spacetime rotation and second, the stability of the motion within the rotating spacetime. Turning to Einstein's equations, it is reasonable to model such galaxies using a stationary axisymmetric metric,

$$\begin{aligned} ds^2 &= -A(cdt)^2 + B(d\phi - \omega dt)^2 + Cdr^2 + Dd\psi^2 \\ &= -(A - \frac{B\omega^2}{c^2})(cdt)^2 \\ &\quad - 2\frac{B\omega}{c}d\psi(cdt) + Bd\phi^2 + Cdr^2 + Dd\psi^2 \end{aligned} \tag{17}$$

with an energy-momentum tensor of the form

$$\mathbf{T}^{\mu\nu} = (\rho_{vac}c^2 + p_{vac})\frac{u^\mu u^\nu}{c^2} + p_{vac}\mathbf{g}^{\mu\nu} + \rho_m\, c^2\frac{v^\mu v^\nu}{c^2} \tag{18}$$

Beginning with the rotation, any small volume of the vacuum will respond to the total gravitation field in the same way as does a material particle. That means we can analysis its motion using the usual geodetic equations.

$$\begin{aligned} \frac{du^0}{dt} &= \Gamma^0{}_{00}\, u^0u^0 + 2\Gamma^0{}_{01}\, u^0u^1 + \Gamma^0{}_{11}\, u^1u^1 = 0 \\ \frac{du^1}{dt} &= \Gamma^1{}_{00}\, u^0u^0 + 2\Gamma^1{}_{01}\, u^0u^1 + \Gamma^1{}_{11}\, u^1u^1 = 0 \\ \frac{du^2}{dt} &= \Gamma^2{}_{00}\, u^0u^0 + 2\Gamma^2{}_{01}\, u^0u^1 + \Gamma^2{}_{11}\, u^1u^1 = 0 \\ \frac{du^3}{dt} &= \Gamma^3{}_{00}\, u^0u^0 + 2\Gamma^3{}_{01}\, u^0u^1 + \Gamma^3{}_{11}\, u^1u^1 = 0 \end{aligned} \tag{19}$$

The first two of these are satisfied identically because all the connections vanish which is just a consequence of our assumption of a stationary metric. Without giving the details, the last two have the solution

$$\dot{\varphi}_{vac}[r,\psi] = \omega[r,\psi]. \tag{20}$$

where $\omega[r,\psi]$ represents the rotation of the galaxy. What we find is that the curvature of the vacuum must rotate. This is an example of what is known as inertial frame dragging. Appling the same set of equations to the stars, we obtain the same result so the stars are seen to rotate with the vacuum and hence, are a rest.

The original problem that motivated the idea of dark matter was to explain why galactic clusters didn't fly apart. From a vacuum energy point of view, they don't fly apart because the stars and galaxies are, in fact, at rest.

The next step would be to solve Einstein's equations with the above metric but, unfortunately, we have not been able to do so because of the lack of sufficient computer power. Taking a Newtonian approach instead, we consider the balance of forces acting on a star at rest in the plane of the galaxy with a torus of vacuum energy lying at its outer edge co-planer with the galaxy. Again, without giving the details which are presented in [1], we obtain a formula for the vacuum energy density of the torus,

$$\rho_{vac}c^2 = \frac{|h_2(\xi)|}{2\pi^2\zeta(\zeta-1)^2 h_1(\xi,\zeta)}\left(\frac{M_G c^2}{R_G{}^3}\right) jm^{-3}. \tag{21}$$

Here, $\xi = r/R_G$ is the distance from the center of the galaxy and $\zeta = L/R_G$ defines the geometry. L is the distance from the center of the galaxy to the center of the torus. Figure 12 shows this result graphically. We see that the results are nearly

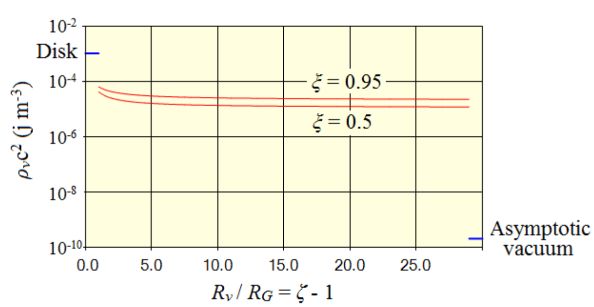

Fig. 12. Solution of (**??**) for two values of ξ.

independent of the sampling position and that the required vacuum energy density is only around 1% of the mass energy density of the galaxy.

What this also shows is that the vacuum energy density near large structures must be considerably larger that it is far from matter which is consistent with the notion that dark matter always seems to hover close to ordinary matter. Recalling the results of the previous section, this is also consistent with the idea that any concentration of matter must also involve a concentration of vacuum energy.

We now wish to apply this result to galaxy clusters. Note that (21) is the product of two factors. The first depends only on the geometry and the second on the mass ratio of the structure. Applying this to a typical galaxy cluster yields a value of $\rho_{vac}c^2$ which is not significantly different from the background value of (7). The fact that the required energy density is small allows plenty of room for adjustments of the geometric factor to more closely model the geometry of a cluster.

We find then that vacuum energy can readily account for the observed rotation of stars in galaxies and galaxies in cluster. The conclusion is that *dark matter is vacuum energy*.

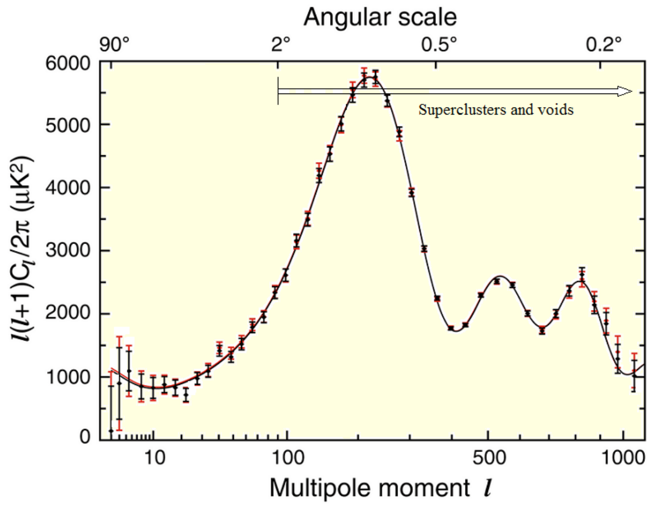

Fig. 14. The power spectrum of the CMB anisotropy from [3]. Angles are related to the moment by $l = \pi/\theta_{\rm rad} = 180/\theta_{\rm deg}$.

VII. CMB Spectrum

In this section we will show that the prominent features of the CMB spectrum can be understood in terms of the existence of large structures such as superclusters on the one hand, and uncertainties left over from the initial inflation, on the other. Figure 13 shows the well-known CMB anisotropy map. A portion of the map has been enlarged in the lower rectangle and two angular size references are also included. The spectrum is shown in Figure 14, For angular dimensions of 2° or less, we will show that the features are a consequence of physical structures. In [1], we show that the anisotropy map on the largest scales cannot be random so the apparent structures of angular size greater that 45°are also, in fact, due to actual structures. In between, it is a consequence of scale-invariant random variations in the vacuum energy density that were set at the end of the initial inflation. Refer to the paper for the details.

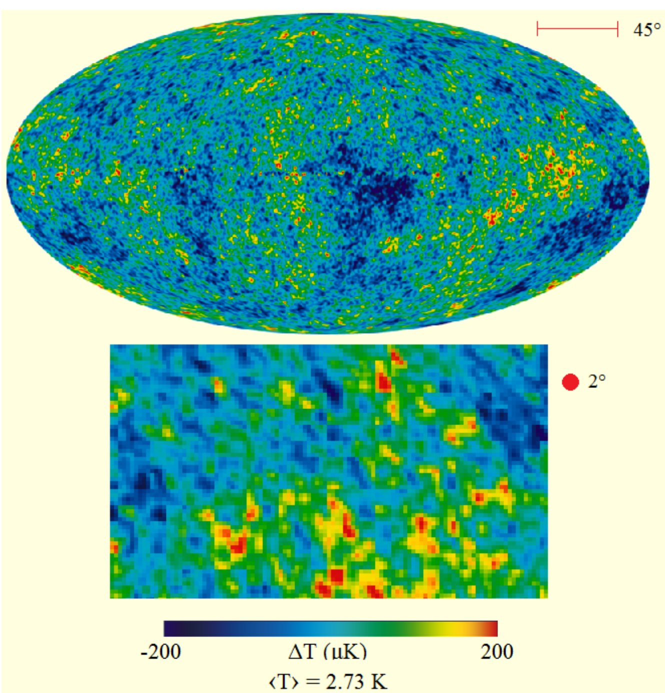

Fig. 13. CMB anisotropy, [2].

The CMB we receive was emitted by a spherical shell whose radius is fixed by the coordinate distance of Figure 3 when evaluated at the time of recombination. Thus, $S(t_{rec}) = 0.6\,a(t_{rec})$. For a structure of size, $D\,(t_{rec})$, the subtended angle would then be

$$\theta = \frac{D(t_{rec})}{S(t_{rec})}\,(360/2\pi). \tag{22}$$

which becomes

$$\theta = \frac{D(t_0)}{0.6\,a(t_{rec})}\,\frac{a(t_{rec})}{a(t_0)}\,(360/2\pi) = 95.5\frac{D(t_0)}{a(t_0)}\,\text{deg}\,. \tag{23}$$

The important fact used here is that light travels alone lines of constant angle so the subtended angle is independent of time. In Table I, we list the angles subtended by various structures.

Object	θ (deg)
Milky Way	.0001
Groups	.007 - .013
Clusters	.013 - .065
Superclusters	0.2 – 2.0
voids	0.6 – 1.6
Extreme structures	> 45

TABLE I
Angular sizes of various structures.

From this, we see that superclusters and voids are large enough to account for the peaks of the spectrum and in fact, these are the only known structures that are large enough. Of course, not even stars existed at the time of recombination so what we are speaking of are not their present-day manifestations but instead, the precursors that were embedded in matter densities at the time of nucleosynthesis.

Before proceeding to show in detail that superclusters and voids are the source of the large peak of the spectrum, we will discount the commonly held belief that acoustic oscillations are responsible for the peaks. The argument is very simple. At the time of recombination, the angular distance a signal could have traveled was $0.05°$ which is vastly too small to account of any sort of cooperative motion on the scale needed to explain the spectrum especially when one remembers that signals must traverse the region of interest repeatedly in order to produce an oscillation. It is also a fact that as one goes back in time, the signal distance becomes smaller relative to the size of any structure so an oscillation at an earlier time is even more impossible. By the same token, it is also the case that acoustic oscillations had nothing to do with the origin of superclusters and voids.

In the paper, we present the details of the calculation needed to determine the the shape of the peak that would result from the existence of an ensemble of structures of a given size. When the resulting formula is plotted against the spectrum using a midpoint value for the size of a superstructure, the curve matches the first peak fairly closely. Superstructures, however, exist with a range of sizes so it is necessary to recompute the spectrum for a spectrum of sizes. In Figure 15, we show a plot of 71 known superclusters and voids. We

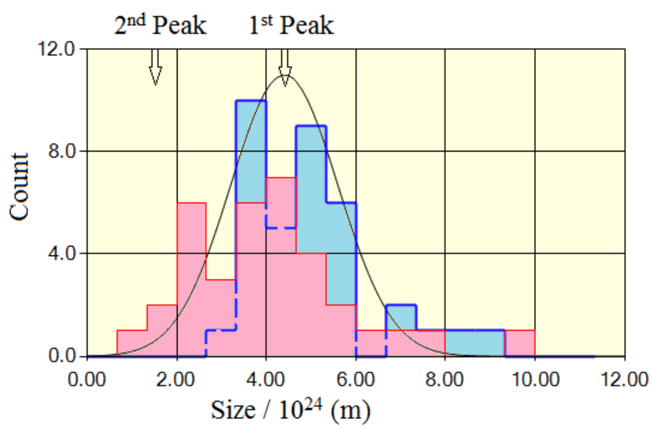

Fig. 15. Count of observed superclusters (red) and voids (blue).

assumed the Gaussian distribution shown and the resulting spectrum is shown in Figure 16. We find that the position of the peak is correct. The shape of the predicted peak is slightly broader than the observed peak but that is quite likely due to the fact that we assumed that the superclusters were spherical which is certainly not the case. The magnitude of the predicted peak was adjusted to match the observed peak and is not a prediction. We note too that the 2nd peak does not correlate with the size of any structure which is strong evidence that it results from multipole distributions within the superclusters and voids. Referring back to Figure 13, we see in the magnified plot that the $2°$ objects generally have a single temperature but there are some with variances which supports the idea of a multipole distribution within the superclusters.

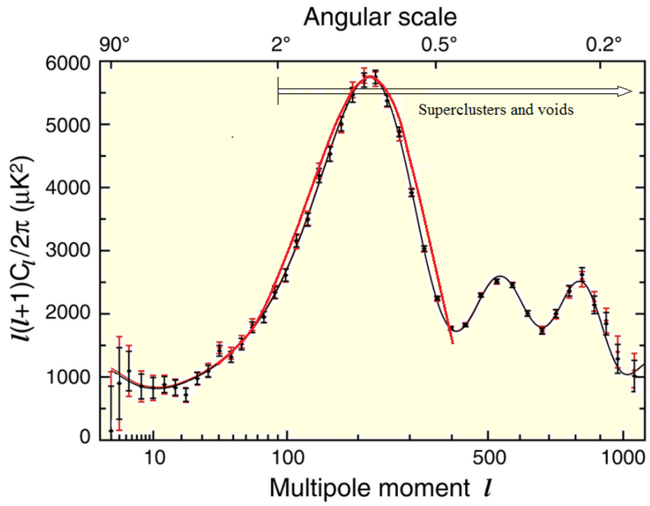

Fig. 16. Ensemble average supercluster/void CMB spectrum.

Since there is nothing in the list with an angular size of $0.2°$, the same probably holds true for the 3rd peak as well.

The remaining problem is to explain the flat spectrum between $2°$and $45°$. Without going into the details, we show in the paper that at the end of the initial inflation, each Plank-sized region of the vacuum would have had variance in its energy density resulting from the uncertainties. These variances would have remained over time and further, the expectation value of the variances would have been scale invariant. Taking this as the source, we calculated the spectrum with the result shown in Figure 17. The conclusion is that

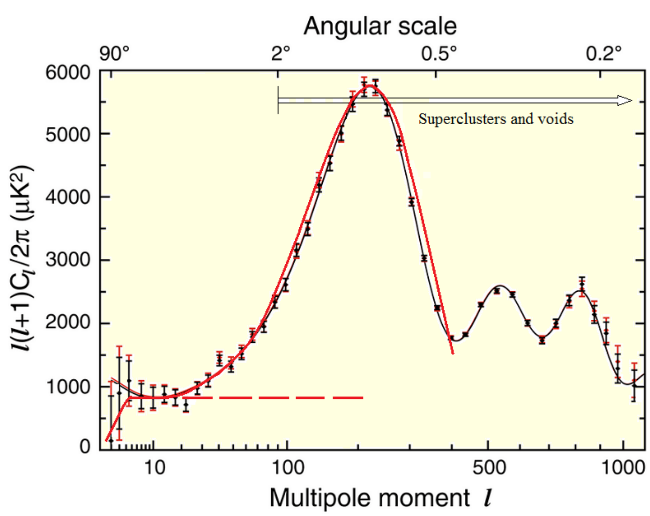

Fig. 17. Large angle spectrum of the CMB.

uncertainties during the initial inflation and the precursors of the superclusters and voids are responsible for the spectrum within the range shown in the figures.

VIII. Tying Things Together

We will now draw all the preceding ideas together to build a complete picture of the origin of cosmic structures.

We showed earlier that accretion initiated by small fluctuations in an otherwise uniform distribution of ordinary matter is impossible so the idea that accretion is the primary source of cosmic structures is wrong. The really insurmountable problem with accretion, however, is that no process that involves communication could account for structures as large as or larger than superclusters.

The conclusion we reached was that *the existence of all large structures was imprinted on spacetime during the initial inflation and it was this imprint that regulated the creation of neutrons and antineutrons at the time, t_n, in such a manner that the resulting distribution eventually developed into the structures we now see.*

We have argued that uncertainty was a major factor during the inflation. At the same time, we now see that very large *smooth* structures also came into existence during the inflation and that the matter/antimatter asymmetry factor had everywhere the same "sign." Thus, the inflation exhibited a simultaneous mix of highly random and highly structured components with, based on the CMB spectrum, the magnitude of structured components on the order of 10^{-5} relative to the overall energy density. We find then, that the entire present-day cosmic web structure was imprinted on the vacuum during the inflation and it came into existence more or less in its final form during nucleosynthesis. Figure 13 is not just a map of the CMB anisotropy but is also a photograph of the vacuum as it existed at the end of the inflation.

We will now present some observational evidence that supports these ideas. In Figure 18, we show a plot of the count of all cosmic structures as a function of their size. What is remarkable is that aside from the extreme structures, all cosmic structures with their vast differences in size and numbers lie on a power law curve and this holds all the way down to the stars. The fact of this relationship points to a common origin for all structures. The extreme structures fall below this line but this is simply a consequence of the finite size of the universe. The dashed line, in fact, shows the count of structures of a given size that would fill the universe. We see that superclusters fall on both lines so in an order of magnitude sense, they, like the extreme structures, fill all space.

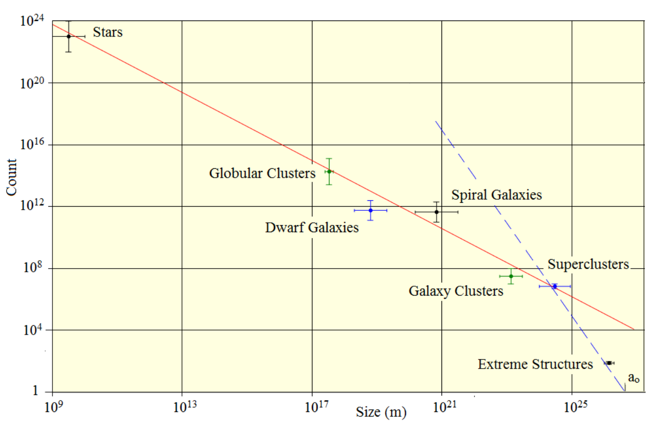

Fig. 18. Count of structures vs size.

A fit to the power law curve has the following form,

$$C(s) = 5.7x10^6 (s_{Sc}/s)^{1.1} \tag{24}$$

where we have scaled by the average size of a supercluster.

What we are going to argue now is that these results not only support the notion of a Plank era imprint being responsible for the distribution of structures but also that the imprint is correctly described as a fractal geometry.

The formula for the dashed line is

$$C_{filled}(s) = (a_0/s)^3. \tag{25}$$

The significant factor here is the power of 3. For the count of objects on a two-dimensional surface, the power would be 2. The idea of a fractal dimension extends this concept to situations in which the power can have any value, not just an integer but this is exactly the form of (24) so we find that the structure imprint had a fractal dimension of 1.1.

It is generally true that the fractal dimension of any system is larger than the geometric dimension of that same structure so it follows that the cosmic structure must be 1-dimensional or in other words, it must consist of filaments.

In Figure 19, we show the count as a function of their masses.

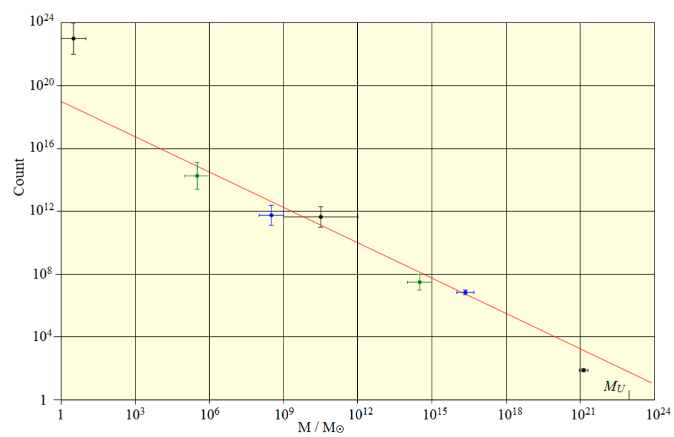

Fig. 19. Count of structures vs mass.

We see that, with the exception of stars, the scatter from the two curves is small which is an indication that subsequent interactions between and within the structures had only a secondary effect on their present-day sizes. Stars are the obvious exception since their formation is well understood to be an ongoing process of accretion but this was not the case for the original stars which own their origin to the same imprint that was responsible for all the larger structures. To see this, we point out that to create a star directly out of the background density of particles, a volume roughly the size of a globular cluster would have been required which makes such an accretion origin highly unlikely.

Another point to notice is that the structures have distinct sizes with no overlap. If accretion was the process by which these were formed, one would expect a continuum of sizes instead.

Nucleosynthesis gives us another means of testing these ideas. What we found earlier is the outcome of nucleosynthesis is moderately sensitive to the assumed initial particle density. In particular, if a low density is assumed, we found that the relative density of ^4He is much lower that is the case with higher densities. Thus, if the proto-voids existed at the time of nucleosynthesis as we are asserting, then the present-day relative density of ^4He in isolated regions of large voids would be significantly lower that the value of 24% found in high density regions. Unfortunately, at the present time, we have not been able to locate the data needed to settle the issue.

Over time, researchers have come to appreciate from the limitations imposed by causality that something in addition to visible matter was needed to explain the structure of the cosmic web. To fix things up, the original concept of dark matter was extended to play that role. We have shown here that the missing piece is, in fact, vacuum energy and hence we complete the identification of dark matter as vacuum energy begun earlier.

So, here at the end, we are back where we started. The big mystery is the Plank era inflation. We have no clear idea of how it all worked but we have demonstrated that it was responsible for the universe we observe.

IX. Conclusion

This new model presents an unified model of cosmology that solves or points to a solution of the major problems of cosmology.

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