The Formation of All Cosmic Structures, both Large and Small

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I am presenting here an entirely new model of cosmology. Unfortunately, because of time limitations, I will be restricted to presenting just a list of results without being able to provide much in the way of justification. The details can be found in the papers listed below.

A Different Cosmology – Thoughts from Outside the Box
Journal of High Energy Physics, Gravitation and Cosmology, Vol. 6, No. 3 July 30, 2020

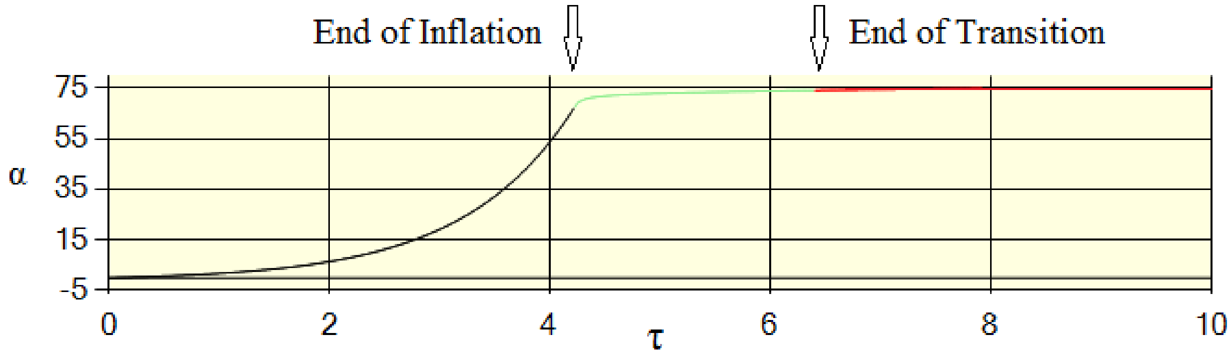
A Different Cosmology – Summary
ResearchGate

Plank Era

The universe began with a Plank era exponential inflation of the scaling;

- The curvature of the vacuum was the only existence.
- Time, distance, and vacuum energy were uncertain and normal causality did not exist.
- The energy density of each Plank-sized cell was uncertain.
- The maximum realizable vacuum energy density was the Plank energy density.
- The inflation ended at the point in time when the uncertainty because small relative to the age of the universe – at about $t_I = t_P\, e^{\tau_I}$ with $\tau_I \simeq 4.2$.

Following the inflation, a transition period occurred that ended at a time of about $t_T = t_P e^{\tau_T}$ with $\tau_T \simeq 6.6$. By the end of the transition, the uncertainties had become very small and the evolution was thereafter described by a new solution of Einstein's equations based on a vacuum with time-varying curvature. Importantly, the subsequent evolution was subject to causality. The model has no free parameters which means that the inflation model is constrained because it must match that curve at the end of the transition era. The scaling in the figure is defined by $a(t) = a_P\, e^{\alpha(\tau)},\ \tau = \ln(t/t_P)$.



Einstein Era

This new model of the vacuum is based on the idea that the curvature varies with time. Two important results follow:

- The curvature is proportional to the vacuum energy density and these always have their maximum possible values.
- The model predicts a present-day exponential acceleration of the scaling.

The principal formulas are:

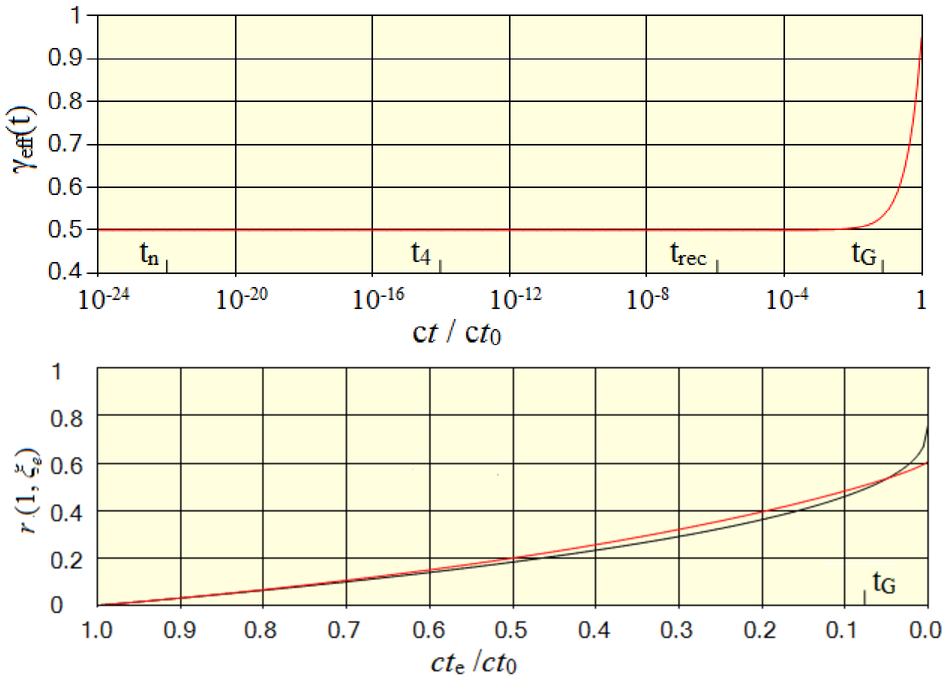
$$a(ct) = a_* \left(\frac{ct}{ct_0}\right)^{\gamma_*} e^{\frac{ct}{ct_0}c_1}; \qquad k(ct) = \frac{1}{2}\gamma_h\, a(ct)^2 \kappa \left(\rho c^2(ct) + p(ct)\right); \qquad \rho c^2(ct) + p(ct) = \frac{2\bar{k}_0}{\kappa (ct_0)^2 \gamma_h} \frac{(ct_0)^2}{(ct)^2}$$

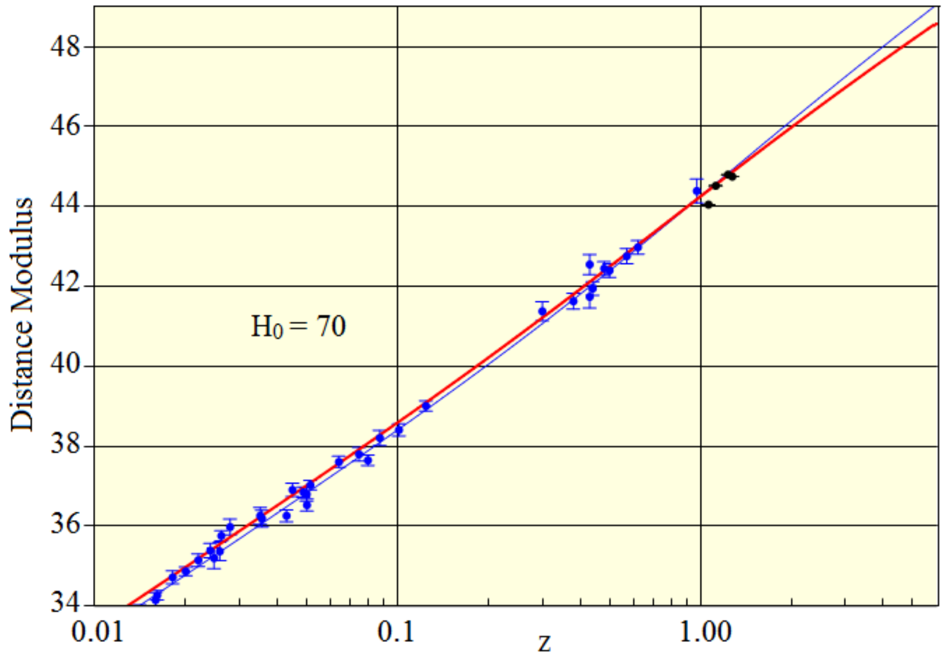
The present day value of the curvature is $k(ct_0) = 1.41$. Note that the scaling is independent of the energy density. The acceleration is a consequence of the time variation of the curvature and has nothing to do with dark energy or a cosmological constant. (As a aside, the predicted vacuum energy density differs from the accepted dark energy value by a factor of about 3.) There are only two parameters in this model. One is fixed by the value of the present-day Hubble parameter and the other by value of the CMB energy density at the time of nucleosynthesis.

The standard model does not actually predict anything solely on the basis of being a solution of Einstein's equations. By choosing different parameters, any sort of evolution is possible. In the new model, this is not the case. There are no free parameters and only one evolution is possible.

Some results are shown in the next slide.

The upper-left figure shows the effective scaling, $\gamma_{eff}(ct) = ct\,\dot{a}(ct)/a(ct) = \gamma_* + c_1\,(ct/ct_0)$. The lower-left figure shows the coordinate distances of sources that emitted a signal at the indicated time which we now receive at the present time (red curve). In contrast to a universe with constant curvature (black line), there is a limit on our ability to detect distance sources. No matter how far back we look in time, sources with coordinate distances greater than about 0.6 cannot be detected. (We have scaled the radial coordinate so that it ranges in value from 0 to 1.) The right-hand figure show the predicted luminosity distance with $H_0 = 70$. (This is a slightly larger value of H_0 than was used in the original paper.) The result shown is a prediction with no free parameters and clearly the fit to the data is quite good. The blue line is the ΛCDM result which is not a prediction at all but is instead the result of curve fitting.





Nucleosynthesis

Working backwards from observations of the oldest galaxies allows us to estimate the abundances of the light elements that were formed by the nucleosynthesis process. Working backwards again using known reactions, we can determine that nucleosynthesis began with a mix of about 80% protons and 20% neutrons. That, however, is as observations can take us. Observations cannot tell us anything about the origin of the initial mix of protons and neutrons.

It is widely believed that the process began very early with radiation at a very high temperature and that the proton and neutrons were the result of various processes described by field theory. This theory, however, has a number of problems, not the least of which are that;

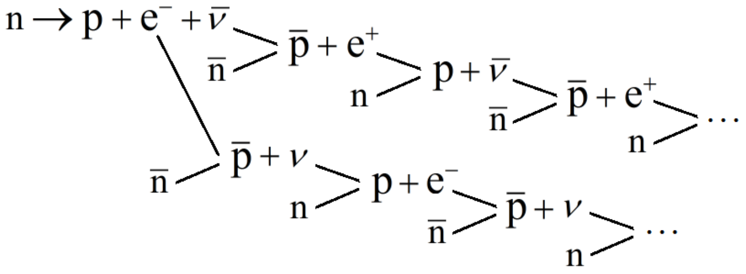
- It completely ignores causality.
- It cannot explain the matter/antimatter asymmetry of the universe.

It is also far too complex for a process that occupied a time period of less than 10^{-5} s. It is a fact, for example, that it wasn't until a time of 10^{-25} s that a signal could have traveled the diameter of a neutron so the interactions that underlie field theory, the propagation of signals, etc, could not have begun to occur prior to that time. There is no evidence to support the radiation-based theory and we assert that it never happened.

In its place, we propose a much simpler model that accounts for both the CMB and nucleosynthesis as well as for the matter/antimatter asymmetry. The basic idea is that there was no existence other than the vacuum prior to a time of about 10^{-5} s and that at that time, about 0.1% of the vacuum energy was converted into neutron/antineutron pairs with a very small bias towards neutrons.

Using the formula for the energy density of the vacuum given earlier and assuming that the pair production occurred at the point in time when the vacuum energy density equaled the equivalent energy density of a neutron, we determine that the event occurred at a time of t_n=4.3x10^{-5} s. Working backwards from a present-day average number density of baryons of 2 m^{-3} and the known CMB temperature, we determine that at t_n, the number densities of baryons and photons were 7.7x10^{33} m^{-3} and 1.5x10^{42} m^{-3} respectively. This energy density of the radiation amounts to about 0.1% of the vacuum energy density and the total particle energy density was about a factor of 10^{-7} smaller than that. In contast to the standard model, we will argue that these values varied from one region to another in accordance with the present-day distribution of matter in the universe.

In outline, the process went as follows. First, pair production of neutrons and antineutrons began. Immediately, a few neutrons/antineutrons underwent β decay releasing neutrinos. This initiated a cascade of reactions that produced protons and antiprotons. At the same time, pair annihilation began and the resulting photons, after thermalization, became the CMB. The asymmetry can be accounted for by the existence of very small bias embedded in the vacuum pair production process; to wit, 2-4 extra neutrons for every 10^8 neutron/antineutron pairs.



Subsequent to the creation, matter must be introduced into earlier Einstein's equations. The only change is to add the matter density to the sum of the vacuum energy density and pressure. The important consequence of this is that, because the sum is a fixed function of time only, structure formation initiated by small fluctuations in the matter density is impossible because any small change in the matter density is immediately cancelled by a change in the vacuum density.

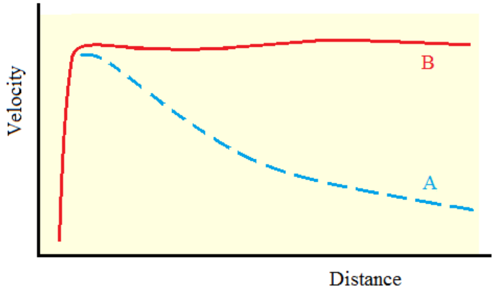
Nucleosynthesis proper proceeds along the lines of the standard model and the results are the same with the exception of the final density of Lithium. We show that the so-called Lithium problem is a consequence of the omission of several known Li reactions from standard model calculation and when these are included, the Li problem vanishes.

Dark Matter

Dark matter was originally proposed to explain the motion of galaxies in galaxy clusters and later to explain the velocity distribution of the stars in spiral galaxies. Since then, it has become something of a catch-all to fix up the calculations of various cosmic phenomena. *What we show is that dark matter is, in fact, vacuum energy*.

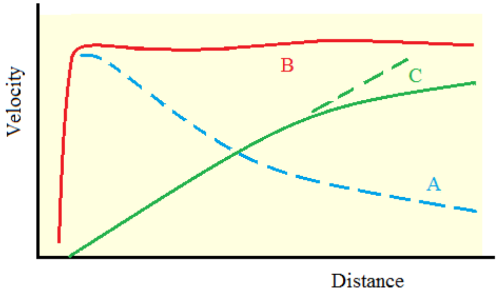
Spiral Galaxies

We start with the spiral galaxy velocity problem. A typical velocity distribution is shown in the upper figure. The problem is that the observed distribution, curve A does not match the expected distribution, curve B. To get a hint towards the solution of this problem we subtract the two curves to obtain curve C in the lower figure. What this shows that the velocity distribution can be understood in terms of some normal orbital motion riding on a rigidly rotating background.



Consider now the usual metric for a stationary axial-symmetric distribution of stars plus the vacuum. The LHS has the usual form but the RHS now contains contributions from both the vacuum and the stars.

$$T^{\mu\nu} = (\rho_{vac}c^2(ct,r) + \rho_m c^2(ct,r) + p(ct,r))\delta_0^\mu \delta_0^\nu + p(ct,r)g^{\mu\nu}$$



Turning to the geodesic equations for the vacuum, we find that the vacuum rotates at the same rate as the overall rotation of the galaxy and furthermore, that the particles (stars) also rotate at that rate. The conclusion is that the stars (or at least the outer ones) are at rest and are being carried along by the rotation of the vacuum. The common term for this phenomenon is inertial frame dragging.

We now need to consider the equilibrium of this model. We have not yet been able to solve the general equations even numerically so we have been forced into taking a Newtonian approach. By balancing the forces on a star from both the thin disk of the galaxy and an outlying torus of vacuum energy, with the stars are rest, we find that equilibrium requires a vacuum energy density within the torus equal to about 1% of the equivalent energy density of the galactic disk. Although this value is small relative to the galaxy energy density, it is huge compared to the background vacuum energy density. We find that vacuum energy is as much a part of galactic structure as matter. This leaves us with the problem of explaining this relatively large vacuum energy density. We have already shown that accretion cannot account for it so we must look elsewhere further in the past.

Galaxy Clusters

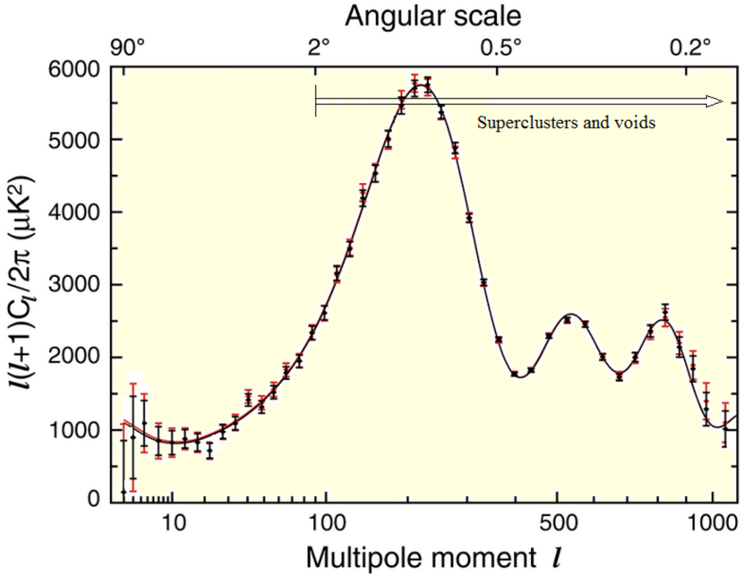
Applying this same result to galaxy clusters, we find that equilibrium requires an energy density essentially the same as the background value which at the present time is 2.1×10^{-10} j m^{-3}.

Dark matter was originally propose to prevent the galaxies from flying off into space. The reality is that they don’t fly off into space because *they are, in fact, at rest in a rotating vacuum.*

The phenomena attributed to dark matter are, in fact, a consequence of vacuum energy.

CMB Spectrum

The CMB that we receive today was emitted by a spherical shell whose radius was fixed by the coordinate distance shown earlier when evaluated at the time of recombination. Thus, $S(t_{rec}) = 0.6\, a(t_{rec})$. The angular size of any source would then be given by $\theta = \frac{D(t_{rec})}{S(t_{rec})}(360/2\pi)$ degs where D is the size of the source. An important property of the vacuum metric is that there are no off-diagonal components linking time and the angular coordinates with the consequence that the angle between two approaching signals does not change. Curvature is entirely a radial phenomenon. That being the case and because the universe is a rest, we can move this equation ahead to the present day. Thus, $\theta = 95.5\frac{D(t_0)}{a(t_0)}$ deg.

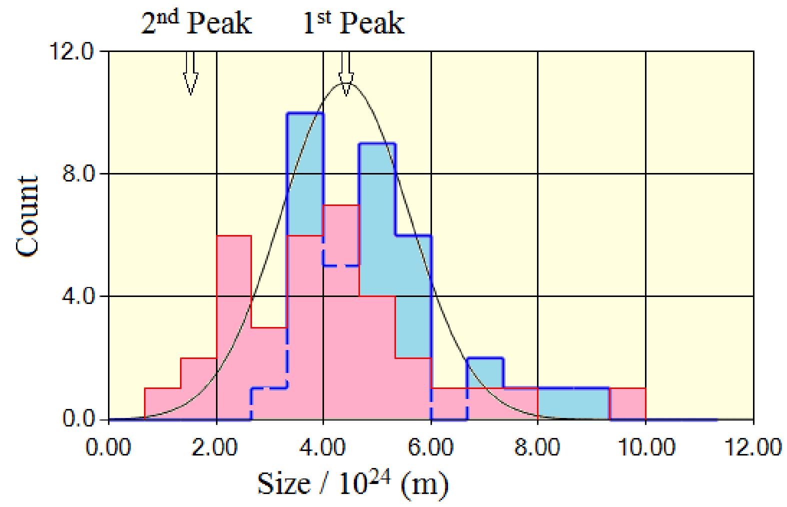


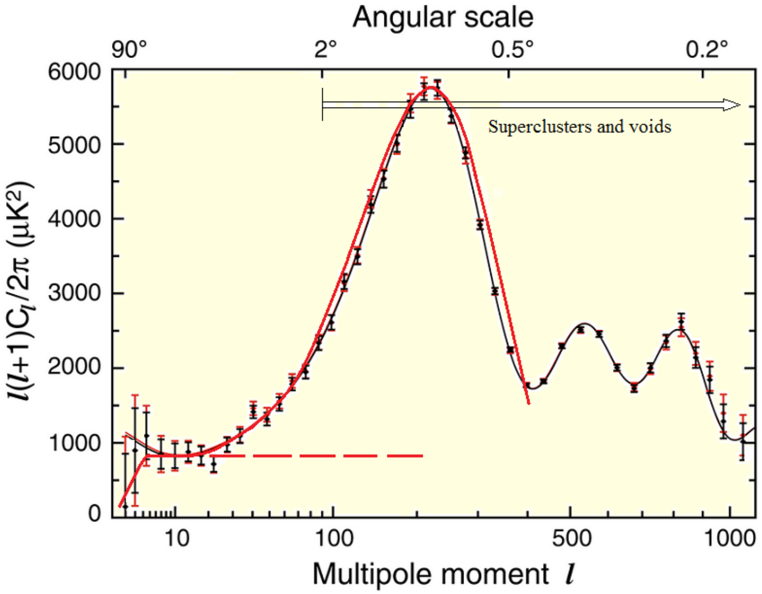
From the figure to the left, we see that the first large peak has an angular size of about 1 deg. In the table on the right, we list the angular size of various structures. From this, we find that superclusters are the only structures large enough to account for the peak.

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
Signal (ct)	0.05

At this point, we can discount the widely accepted notion that the peak is a consequence of acoustic oscillations. This is another case in which a simple argument based on causality eliminates the possibility. From the table, the distance any signal could have travelled at time t_{rec} yields an angular size of 0.05 deg which is vastly smaller that the size of the peak so no oscillation, which is a cooperative phenomenon involving continuous signal exchange, could ever account for something as large as a supercluster.

We next performed a statistical calculation to determine the spectrum to expect from the known distribution of supercluster (and void) sizes. This distribution is shown in the upper figure and the resulting spectrum in the lower figure.





What we find is that superclusters result in a perfect match to the location of the peak as well as a close match to its shape. The difference in the shape is likely due to the fact that a spherical shape was assumed in the calculation whereas we will know that superclusters are far from spherical. The height of the peak, on the other hand, was adjusted to match the spectrum and is not a prediction.

Also shown is our prediction of the flat spectrum out to angles of about 45 deg based on uncertainties locked into Plank-sized regions at the end of the initial inflation.

This now lands us with a problem. How can superclusters be responsible for the spectrum at time t_{rec} when, according to the standard viewpoint, not even stars were yet in existence? Nevertheless, the spectrum tells us they were there and since superclusters are made up of galaxy clusters which, in turn, are made up of galaxies and so on, all structures must have been in existence at that time.

Given that fact, we must look further into the past to understand their origin.

Tying Things Together

The adjoining table lists the sizes of various structures at t_{rec} and t_n. Comparing the sizes with the signal distance, we see that at time t_{rec}, signal exchange was possible over the dimensions characteristic of the smaller structures but was clearly not so for superclusters. Looking now at the values at t_n , we find that the causality problem has only gotten worse since now, none of the structures have sizes within the signal distance. Since the only era in which causality was not expressed was during the Plank inflation, we conclude that,

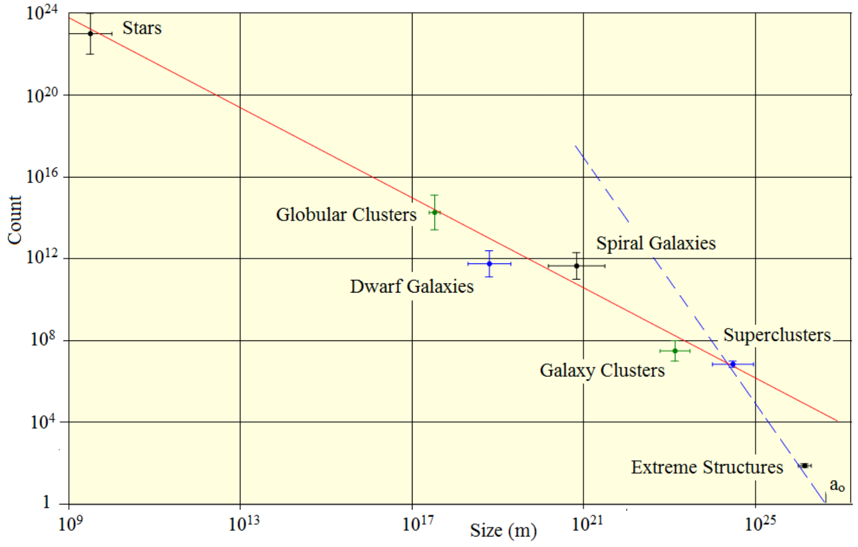
Object	$t_{rec} = 4.9 \times 10^{11}$ s	$t_n = 4.3 \times 10^{-5}$ s
Signal (ct)	1.5×10^{20} m	1.3×10^{4} m
Globular Cluster	$(1.6 – 3.1) \times 10^{14}$ m	$(1.6 - 2.9) \times 10^{6}$ m
Dwarf Galaxy	$(1.4 - 14) \times 10^{15}$ m	$(1.3 - 13) \times 10^{7}$ m
Spiral Galaxy	$(1 - 21) \times 10^{17}$ m	$(1 - 20) \times 10^{9}$ m
Group	$(2 - 4) \times 10^{19}$ m	$(2 - 4) \times 10^{11}$ m
Galaxy Cluster	$(4 - 20) \times 10^{19}$ m	$(4 - 19) \times 10^{11}$ m
Supercluster	$(7 - 61) \times 10^{20}$ m	$(6 - 58) \times 10^{12}$ m

The existence of all structures was imprinted on the vacuum during the inflation and that it was this imprint that regulated the creation of neutron/antineutron pairs at the time t_n in such a manner that the resulting distributions of particles eventually developed into the structures we now see.

We saw earlier that uncertainty was a major factor during the inflation with the energy of each Plank-sized cell uncertain to the extent of the Plank energy density but we now see that concurrently, very large *smooth* structures also came into existence. The table gives us the size of these structures but they are even larger that this indicates because the size of a Plank cell at the time t_n was 10^{-17} m so the Plank era structures that resulted in superclusters had dimension on the order of 10^{30} Plank lengths. Comparing with inflation, we find that these were the size of the universe at the end of the inflation and that during the transition, their relative size decreased to the observed relative size of (1-2)/360. The inflation, then, exhibited a mix of highly random and highly structured components with the magnitude of the structured components on the order of 10^{-10} relative to the background energy density. The end result was that all matter structures came into existence at the time t_n more or less in their final form.

We will now consider evidence that supports this result. In the following figure we show a plot of the counts of each type of structure vs their size. What is remarkable is that all structures, aside from the extreme structures, lie on a power law curve. This includes even the stars. This result clearly points to a common origin for all the structures. The formula for the red line is $C(s) = 5.7x10^6(s_{Sc}/s)^{1.1}$ where we have scaled by the size of a supercluster. What we are going to argue now is that not only was the imprint responsible for the cosmic structures, but that it is correctly described as fractal.

The formula for the dashed line is $C_{filled}(s) = (a_0/s)^3$ which is just the count needed to fill all space of objects of size, s. The significant factor is the power of 3. In two dimensions it would be 2. For a fractal geometry, the power can have any value but this is exactly the form of the observed counts so the imprint is a fractal with a dimension of 1.1. It is also the case that the spatial dimension of any system is less that its fractal dimension from which we conclude that the arrangement of the matter of the universe is one-dimensional, or in other words, *the structure is one of filaments, i.e. we come to the cosmic web.*



We note that the structures have distinct sizes with no overlap. If accretion was responsible, one would expect a continuum of sizes. We also see that the scatter from the line is small which indicates that subsequent interactions within the structures such as accretion and compaction were of less importance than their original formation.

We find then, that we are back where we started. To make further progress, we need to understand the Plank era and at this point in time, we don't even have a form of mathematics that would allow us to deal with a spacetime that cannot be described by a differential manifold.