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A Walk on the Fractal Universe

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Abstract:*A fractal is a shape that, when looked at a small part of it, has a similar, but not necessarily identical, appearance to the full shape. Hence, enlarging a smaller portion of the shape will provide iteration in the larger image. Therefore, the use of fractals and fractal-like forms to describe or model the universe has had a long and varied history, which begins long before the word fractal was actually coined. In physical cosmology, fractal cosmology is a set of minority cosmological theories which state that the distribution of matter in the Universe, or the structure of the universe itself, is a fractal across a wide range of scales. More generally, it relates to the usage or appearance of fractals in the study of the universe and matter. A central issue in this field is the fractal dimension of the universe or of matter distribution within it, when measured at very large or very small scales. Hence, since the introduction of mathematical rigor to the subject of fractals, by Mandelbrot and others, there have been numerous cosmological theories and analyses of astronomical observations which suggest that the universe exhibits fractality or is by nature fractal. In recent years, the term fractal cosmology has come into usage, as a description for those theories and methods of analysis whereby a fractal nature of the cosmos is shown.*

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I. Introduction

Fractals are mathematical object that looks the same at any scale, whether it is zoom in or out. When two-dimensional fractals are iterated many times, the perimeter of the fractal increases up to infinity, but the area may never exceed a certain value. A fractal in three-dimensional space is similar; such a fractal could have an infinite surface area, but never exceed a certain volume[1]. This idea of fractals can be utilized to maximize the efficiency of ion propulsion when choosing electron emitter construction and material. If done correctly, the efficiency of the emission process can be maximized [2].Stars crowd together into galaxies, galaxies assemble into clusters, clusters amass to formsuperclusters. Astronomers, probing ever-larger volumes of the cosmos, have been surprised again and again to find matter clustering on ever-larger scales.This Russian-nesting-doll-like distribution of matter has led them to wonder whether the universe is a fractal.The first attempt to model the distribution of galaxies with a fractal pattern was made by Luciano Pietro Nero and his team in 1987[3] and a more detailed view of the universe's large-scale structure emerged over the following decade, as the number of cataloged galaxies grew larger. Pietro Nero argues that the universe shows a definite fractal aspect over a fairly wide range of scale, with a fractal dimension of about 2[4]. The fractal of a homogeneous 3D object would be 3, and 2 for a homogeneous surface, whilst the fractal dimension for a fractal surface is between 2 and 3. The ultimate significance of this result is not immediately apparent, but it seems to indicate that both randomness and hierarchal structuring are at work on the scale of galaxy clusters and larger.The universe has been observed to be homogeneous and isotropic (i.e. is smoothly distributed) at very large scales, as is expected in a standard Big Bang or FLRW cosmology, and in most interpretations of the Lambda-Cold Dark Matter model. The scientific consensus interpretation is that the Sloan Digital Sky Survey (SDSS) suggests that things do indeed smooth out above 100 Megaparsecs [5].An analysis of luminous red galaxies (LRGs) in the SDSS data calculated the fractal dimension of galaxy distribution (on a scales from 70 to 100 Mpc/h) at 3, consistent with homogeneity; but that the fractal dimension is 2 out to roughly 20 Mpc/h [6]. In a paper of 2008 [7]D. Queiros-Conde showed that large-scale structure of galaxies are much better described by a scale-dependent fractal dimension drifting from zero to three at a scale around 55 Mpc/h in the context of a "scale-entropy diffusion equation". It gives a way to estimate the number of galaxies in the universe in agreement with Hubble measurements. Moreover, fractal dimension is varying linearly with scale-logarithm. This means that the geometry of galaxy distribution is a "parabolic fractal". Two years later, the author with M. Feidt[8] showed that the fractal dimension 2 found in numerous studies can be explained as being a problem of measurement. In 2007, [9] Amanda et al. definitively showed that large-scale structure of galaxies was homogeneous beyond a scale around 70 Mpc/h, close to the value found by D. Queiros-Conde. In 2013, astronomers discovered a large quasar group (LQG) that is 1.6 billion light-years in diameter, far larger than allowed by the cosmological principle, which asserts that the universe should be homogeneous at scales this large[10].

II. Literature Review

This In the realm of theory, the first appearance of fractals in cosmology was likely with Andrei Linde's "Eternally Existing Self-Reproducing Chaotic Inflationary Universe"[11] theory, in 1986. In this theory, the evolution of a scalar field creates peaks that become nucleation points which cause inflating patches of space to develop into "bubble universes," making the universe fractal on the very largest scales. Alan Guth's 2007 paper [12] shows that this variety of Inflationary universe theory is still being seriously considered today. And inflation, in some form or other, is widely considered to be our best available cosmological model.

Since 1986, however, quite a large number of different cosmological theories exhibiting fractal properties have been proposed. And while Linde's theory shows fractality at scales likely larger than the observable universe, theories like Causal dynamical triangulation[13] and Quantum Einstein gravity[14] are fractal at the opposite extreme, in the realm of the ultra-small near the Planck scale. These recent theories of quantum gravity describe a fractal structure for spacetime itself and suggest that the dimensionality of space evolves with time. Specifically; they suggest that reality is 2D at the Planck scale, and that spacetime gradually becomes 4D at larger scales. French astronomer Laurent Nottale first suggested the fractal nature of spacetime in a paper on Scale Relativity published in 1992,[15] and published a book on the subject of Fractal Space-Time in 1993[16].

French mathematician Alain Cones has been working for a number of years to reconcile Relativity with Quantum Mechanics, and thereby to unify the laws of Physics, using Noncommutative geometry. Fractality also arises in this approach to Quantum Gravity. An article by Alexander Hilleman in the August 2006 issue of Scientific American[17] quotes Cones as saying that the next important step toward this goal is to "try to understand how space with fractional dimensions couples with gravitation." The work of Cones with physicist Carlo Rivoli[18] suggests that time is an emergent property or arises naturally, in this formulation, whereas in Causal dynamical triangulation,[19] choosing those configurations where adjacent building blocks share the same direction in time is an essential part of the 'recipe.' Both approaches suggest that the fabric of space itself is fractal, however.

On the 10th of March 2007, the weekly science magazine New Scientist featured an article entitled "Is the Universe a Fractal?"[9] on its cover. The article by Amanda Getter focused on the contrasting views of Pietro Nero and his colleagues, who think that the universe appears to be fractal (rough and lumpy) with those of David Hogg of NYU and others who think that the universe will prove to be relatively homogeneous and isotropic (smooth) at a still larger scale, or once we have a large and inclusive enough sample (as is predicted by Lambda-CDM). Getter gave experts in both camps an opportunity to explain their work and their views on the subject, for her readers [9].

This was a follow-up of an earlier article in that same publication on August 21 of 1999, by Marcus Chowan, entitled "Fractal Universe" [10]. Back in November 1994, Scientific American featured an article on its cover written by physicist Andrei Linde, entitled "The Self-Reproducing Inflationary Universe"[20] whose heading stated that, recent versions of the inflationary scenario describe the universe as a self-generating fractal that sprouts other inflationary universes, and which described Linde's theory of chaotic eternal inflation in some detail.In July 2008, Scientific American featured an article on Causal dynamical triangulation,[21] written by the three scientists who propounded the theory, which again suggests that the universe may have the characteristics of a fractal.

Modern theories of the big bang predict that our local universe came into existence with a brief burst of inflation, in other words, a tiny fraction of a second after the big bang itself, the universe expanded at an exponential rate. It is widely believed, however, that once inflation starts, there are regions where it never stops. It is thought that quantum effects can keep inflation going forever in some regions of the universe so that globally, inflation is eternal. The observable part of our universe would then be just a hospitable pocket universe, a region in which inflation has ended and stars and galaxies formed. "The usual theory of eternal inflation predicts that globally our universe is like an infinite fractal, with a mosaic of different pocket universes, separated by an inflating ocean," said Hawking in an interview last autumn. "The local laws of physics and chemistry can differ from one pocket universe to another, which together would form a multiverse. But I have never been a fan of the multiverse. If the scale of different universes in the multiverse is large or infinite the theory can't be tested".

However, in a paper, Stephen Hawking said this account of eternal inflation as a theory of the big bang is wrong. "The problem with the usual account of eternal inflation is that it assumes an existing background universe that evolves according to Einstein's theory of general relativity and treats the quantum effects as small fluctuations around this. However, the dynamics of eternal inflation wipes out the separation between classical and quantum physics. As a consequence, Einstein's theory breaks down in eternal inflation.We predict that our universe, on the largest scales, is reasonably smooth and globally finite. So it is not a fractal structure" [22].

III. Discussion and Findings

The clustering of galaxies is well characterized by fractal properties, with the presence of an eventual cross-over to homogeneity still a matter of considerable debate. In this letter we discuss the cosmological implications of a fractal distribution of matter, with a possible cross-over to homogeneity at an undetermined scale. The fractal is a perturbation to an open cosmology in which the leading homogeneous component is the CBR (cosmic background radiation). Cosmologyinspired by the observed galaxy distributions, provides a simple explanation for the recent data which indicate the absence of deceleration. M. Joyce, P. W. Anderson, M. Montuori, L. Pietronero, F. SylosLabini in their paper “Fractal Cosmology in an Open Universe”, shown that their model can be extended back from the curvature dominated arbitrarily deep into the radiation dominated era, and discuss qualitatively the modifications to the physics of the anisotropy of the CBR, nucleosynthesis and structure formation [23].

But nowadays, a new astronomy survey refutes the notion.The universe is fractallike out to many distance scales, but at a certain point, the mathematical form breaks down. There are no more Russian nesting dolls, which means; clumps of matter containing smaller clumps of matter — larger than 350 million light-years across. The finding comes from Morag Scrimgeour at the International Centre for Radio Astronomy Research (ICRAR) at the University of Western Australia in Perth and her colleagues. Using the Anglo-Australian Telescope, the researchers pinpointed the locations of 200,000 galaxies filling a cubic volume 3 billion light-years on a side. The survey, called the Wiggle Dark Energy Survey, probed the structure of the universe at larger scales than any survey before it.The researchers found that matter is distributed extremely evenly throughout the universe on extremely large distance scales, with little sign of fractal-like patterns.Scrimgeour explained the process that led to that conclusion. “We placed imaginary spheres around galaxies in the [Wiggle survey] and counted the number of galaxies in the spheres," she explained in a video. "We wanted to compare this to a random homogeneous distribution” — one in which galaxies are spread evenly throughout space — “so we generated a random distribution of points and counted the number of random galaxies inside spheres of the same size” [24].

The researchers then compared the number of Wiggle galaxies inside the spheres with number of random galaxies inside the similar spheres. When the spheres contained small volumes of space, Wiggle galaxies were much more clumped together inside them than were the random galaxies. “But as we go to large spheres, this ratio tends to 1, which means we count the same number of Wiggles galaxies as random galaxies”, Scrimgeour said. That means, matter is evenly distributed throughout the universe at large distance scales, and thus that the universe isn't a fractal.If it had been fractal-like, "it would mean our whole picture of the universe could be wrong," Scrimgeour said [24].

According to the accepted history of the universe, there hasn't been enough time since the Big Bang 13.7 billion years ago for gravity to generate such large structures.Furthermore, the assumption that matter is distributed evenly throughout the cosmos has allowed cosmologists to model the universe using Einstein's theory of general relativity, which does relate the geometry of space-time to the matter spread uniformly within it.Turns out, both assumptions are safe.A paper detailing the findings appeared in a future issue of monthly notices of the Royal Astronomical Society Journal [24].

IV. Conclusion

Our Discussion confirms a conventional picture of the universe, one that is smooth and homogeneous at very large scales, losing its fractal structure when we zoom out far enough. The finding means that astronomers are justified in measuring average quantities over large spatial volumes — there’s no hidden lumpiness messing up the math. This is good news, since a fractal structure at large scales would mean that "Einstein’s equations are being wrongly applied, and our understanding of things like dark energy could be deeply flawed," says the paper’s lead author, Morag Scrimgeour[24].Our current picture of the universe goes like this: hundreds of billions of stars group together to form galaxies, galaxies clump together to form clusters, and clusters clump together to form up the superclusters. In other words, the universe exhibits properties of a fractal — the same "lumpy" pattern is visible whether we’re looking at the galaxy scale or the supercluster scale. The results indicate that in spheres 600 million light years in diameter or larger, about 6,000 times the size of our Milky Way galaxy, there’s no evidence of clustering. They also show a gradual transition from lumpiness to smoothness as you move out from smaller to larger scales. In that sense, the universe looks a lot like snow — made up of fractal flakes but transitioning to a uniform sea of white as step back.

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