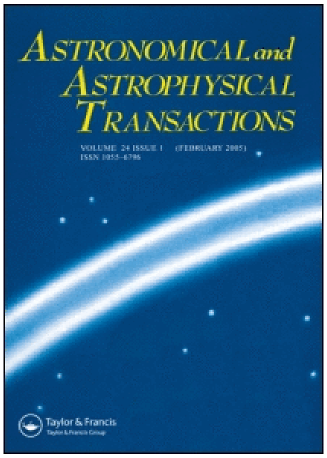

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BATH-FOAM UNIVERSE

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The model of the distribution of matter in the universe proposed in this work combines the advantages of the Swiss-cheese model, being a solution of Einstein's equations and an adequate description of local inhomogeneities in the universe, and of the self-similarity (fractal) approach to hierarchical clustering. It is argued that the model proposed below, which is a generalization of the Swiss-cheese model, describes not only the local aspects of the matter distribution but also its global structure.

KEY WORDS **Distribution of matter, packing of spheres, inhomogeneities, spectrum of masses**

1 INTRODUCTION

Homogeneous models of the universe still play a central role in cosmology. One reason for this is that the Einstein equations become increasingly complicated once inhomogeneities of the matter distribution are introduced. However, there is evidence that the universe is locally inhomogeneous and anisotropic, therefore inhomogeneous models should be given at least as much consideration as homogeneous ones.

The model now known as the "Swiss-cheese" one was formulated by Einstein and Straus (1945) and provided the solution for the gravitational field in the vicinity of a star in the expanding universe, alternative to the usual static solution imbedded in a flat space. There are reasons to think that our space is expanding (and for the positive average density it follows from the field equations). Therefore Einstein and Straus suggested to set a priori that the field around the star must be time dependent. They showed that if we cut a sphere out of the presureless homogeneous FRW universe, then choose our coordinates so that the radius of the sphere does not change with expansion and consider the metric field within the region (denote it by G) replaced by one whose generating mass is localized in the centre of the region G, then within G the field shall satisfy the equations of empty space. It is not affected by the expansion outside of G, and in the space around G the field shall pass into the FRW field with the line element given as

$$ds^2 = c^2\, dT^2 - R^2(T)\{d\omega^2 + S^2(\omega)\, d\Omega\};$$

$$S(\omega) = \frac{1}{\sqrt{K}} \sin(\sqrt{K}\omega), \quad K = 0, \pm 1,$$

where ω is the comoving radial coordinate. Metric coefficients and their first derivatives remain continuous at the boundary of G.

In general, the mass does not have to be singular at the centre of the region G. In this case an object of non-zero size is formed in the central part of the region. The solution within G, outside the central mass, is still a static Schwarzschild solution, while inside the surface of the object the field is FRW, but with the average density different from the density of the surrounding space. More than one hole similar to G can be generated, in which case the properties of the solution stated above still hold true.

It has been recognized that the matter in the Universe is distributed hierarchically (Charlier concept), i.e. large scale distributions of matter (stars, galaxies, clusters of galaxies, superclusters etc.) form a self-similar structure.

2 THE BATH-FOAM

We propose the following model: we start with a homogeneous FRW space. The space is then divided into spherical region of unequal radii so that their collection covers the entire space. It is argued that such a subdivision is possible (Osculatory Packing of Spheres in Three Dimensions). Within each region, mass is removed and the region is replaced with a sphere of smaller radius but higher density so that the total mass is preserved. We will get the first generation of spheres. To implement the idea of hierarchical clustering, we will use the fact that the original Einstein–Straus construction can be applied to any region of FRW independently of its global properties. This allows us to apply the "Swiss–cheese" model to the objects formed in the first generation. We can replace each spherical object with the collection of balls placed in it, and to these balls we can then apply the same generating scheme. For example, this would correspond to collecting galaxies into a cluster. In a similar fashion, we can subdivide our galaxies into a collection of "stars".

There must be some inner cutoff scale since matter is not a collection of points. However, there is no direct evidence for the presence of an outer cutoff, and we can imagine matter being clumped on larger and larger scales, to infinity.

Clumps of matter of the first generation are "moving" away with respect to each other with the Hubble velocity. For the second generation the motion with respect to the centre of the bubble from which it is formed is of Hubble character, with the velocity depending on the average density in the region. Since the density in a clump is higher than average, the expansion is slowed down.

We see that the dynamics of the system is determined by Einstein's equations.

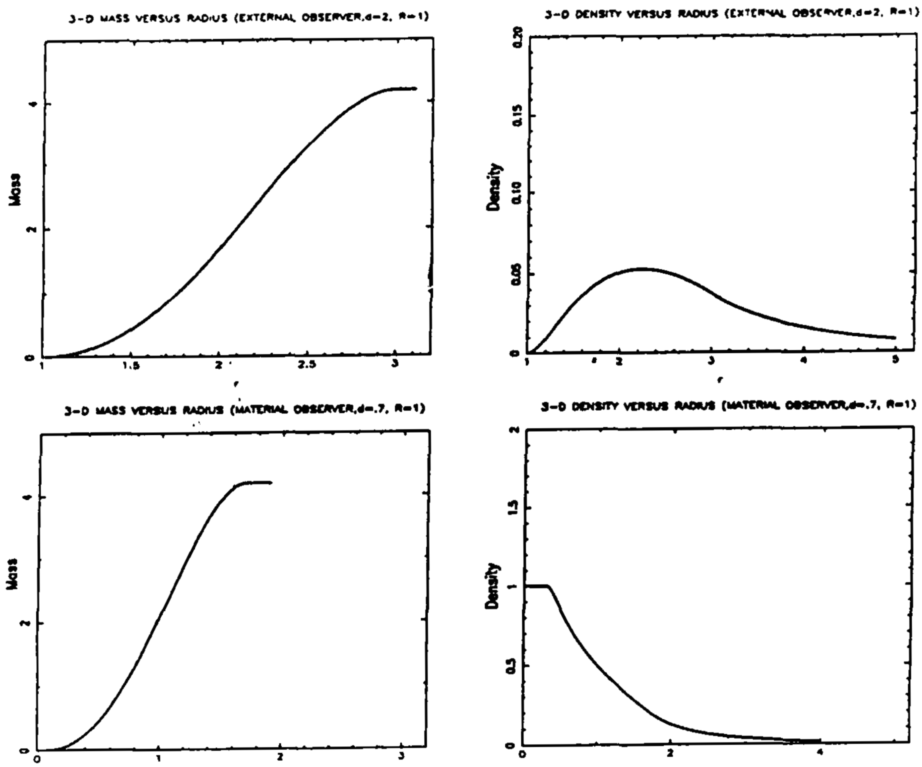

Figure 1 The average mass distribution.

The mass within the spherical hole is uniquely determined by it radius and is given by

$$M = \frac{4\pi}{3} r^3 \rho,$$

where ρ is the radius of the hole or our "bath bubble". Therefore, if we know the radii of the spheres in the n-th generation, then we also know the spectrum of the masses present in it.

The advantage of the bath-foam model is that it allows us to reduce the dynamical problem to the problem of Euclidian geometry.

We have studied the problems of sphere packing in two dimensions (Apollonian packing) and in three dimensions. It is possible to implement packing in such a way that the residual set would be the set of zero volume and therefore of zero mass. There are several of parameters we can vary to get different spectrum of masses.

We have also considered one-dimensional analogies for our model which are related to the known Cantor set.

The packing of spheres is always the first stage of our procedure. The compression of matter in each sphere is the second stage. The simpliest assumption we can make is that the radii of clumps after the compression are proportional to the radii of the spheres in the packing. The compression must be very strong since the average separation between matter aggregates is usually very large compared to their sizes.

In the Bath-foam model there are voids on every scale. If the compression ratio is the same at every stage of construction, the voids will become larger and larger. However, there is an evidence that the ratio of the average separation between stars in a galaxy to the average separation between galaxies themselves is larger than the ratio of the average separation between galaxies to that between clusters of galaxies. Taking this into account would imply that the compression becomes smaller as the scale increases, and in the infinite limit there will be no compression or voids, the distribution will become "smooth".

Studing the osculatory packing of spheres shows that there are "filaments" formed by circles (spheres) tangent to each other and to a given one in which they are inscribed.

In the Figure 1 we present the average mass distribution predicted by our model as it appears to some "material observer" (the one "sitting" within a clump) and to some "external observer" (the one situated in a void). Here R is the radius of the clump and d is the distance from the centre of the clump to the observer.

3 CONCLUSIONS

The bath-foam model is essentially scaleless, it is *locally* inhomogeneous and anisotropic, but it is *statistically* homogeneous and *statistically* isotropic. It shows that there are inhomogeneous and anisotropic models of the distribution of matter in the universe which are consistent and easy to handle.

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