FLUCTUATIONS IN THE IRAS 1.2 JY CATALOGUE

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"It's only galaxies, nothing fundamental." (N. Kaiser)

1. Introduction

In an analysis of the IRAS 1.2 Jy redshift catalogue, with emphasis on the separate examination of northern and southern parts (in galactic coordinates), we found that the clustering properties of galaxies differ significantly in the northern and southern parts, showing fluctuations in the clustering properties at least on scales of $200h^{-1}$Mpc. Our analysis is based on Minkowski functionals, next–neighbour distributions, and the fluctuation of galaxy counts σ^2. In Section 2 we give a brief description of the way we use Minkowski functionals, in Section 3 we present the results for the Minkowski functionals obtained from the IRAS 1.2 Jy galaxy catalogue (the results for next–neighbour distributions and σ^2 will be present in Kerscher et al. [6]), and in Section 4 we discuss our results.

2. Minkowski functionals

We consider a realization $\{\mathbf{x}_i\}_{i=1}^N$ of N points for the process of Large Scale Structure. The realization is given by the redshift–space coordinates of the galaxies in the IRAS 1.2 Jy catalogue [3]. We characterize the properties of this point set with Minkowski functionals as they were introduced into cosmology by Mecke, Buchert and Wagner [8] (see also the article by Schmalzing in this volume). For this purpose we decorate each point $\mathbf{x}_i$ with a ball $B_r(\mathbf{x}_i)$ of radius r. Then we look at the union set $A_r = \bigcup_{i=0}^{N} B_r(\mathbf{x}_i)$. Hadwiger [4] proved that in three dimensions the four Minkowski functionals $M_{\mu=0,1,2,3}(A_r)$ give a complete morphological characterization of a body A_r. They have a direct interpretation in terms of geometrical and topological quantities (see [8] and the article by Schmalzing in this volume). Specific, dimensionless Minkowski functionals $\Phi_\mu(A_r)$ may be constructed by dividing the Minkowski functionals $M_\mu(A_r)$ by N times the functional of a single ball $M_\mu(B_r)$ (i.e. norming the functionals to balls),

$$\Phi_\mu(A_r) := \frac{M_\mu(A_r)}{N M_\mu(B_r)}. \tag{1}$$

For a Poisson process the functionals can be calculated analytically [9]. For spheres with radius r we get for the specific Minkowski functionals:

$$\begin{aligned} \Phi_0^P &= (1-\mathrm{e}^{-\eta})\ \eta^{-1}, & \Phi_1^P &= \mathrm{e}^{-\eta}, \\ \Phi_2^P &= \mathrm{e}^{-\eta}\ (1-\tfrac{3\pi^2}{32}\eta), & \Phi_3^P &= \mathrm{e}^{-\eta}\ (1-3\eta+\tfrac{3\pi^2}{32}\eta^2), \end{aligned} \tag{2}$$

with the mean number of galaxies in a sphere with radius r, $\eta = \overline{n} M_0(B_r) = \overline{n}\ 4\pi r^3/3$, the mean number density $\overline{n}$. As can be seen from Eqs. (2), the Minkowski functionals which are confined to the surface ($\mu = 1,2,3$), are damped by the exponential term $\mathrm{e}^{-\eta}$. This is obvious for a Poisson process. It may be shown that this e^{-r^3} dependence also holds in the case of more general cluster processes for larger radii. We want to investigate the large–scale behavior of the point process, therefore, we look at the surface densities of the specific Minkowski functionals $\Phi_{\mu=1,2,3}$, defined by

$$\phi_\mu(A_r) = \frac{\Phi_\mu(A_r)}{\Phi_1^P(r)}, \tag{3}$$

and thus remove the damping term $\mathrm{e}^{-\eta}$. Since we do not want to introduce any additional uncertainties, we divide by the analytical result for the Poisson process $\Phi_1^P(r)$.

3. Analysis of the 1.2 Jy catalogue

In this section we report on the application of the Minkowski functionals introduced above to a volume limited sample of the IRAS 1.2 Jy galaxy catalogue [3] with limiting depth of $100h^{-1}$Mpc (H_0=100 h km s^{-1} Mpc^{-1}). In Kerscher et al. [6] we discuss how to correct for boundaries. There we also look at a deeper sample, and compare with a simulation. We additionally use the next neighbour statistics and the fluctuations of galaxy counts σ^2 as statistical tools and confirm our results.

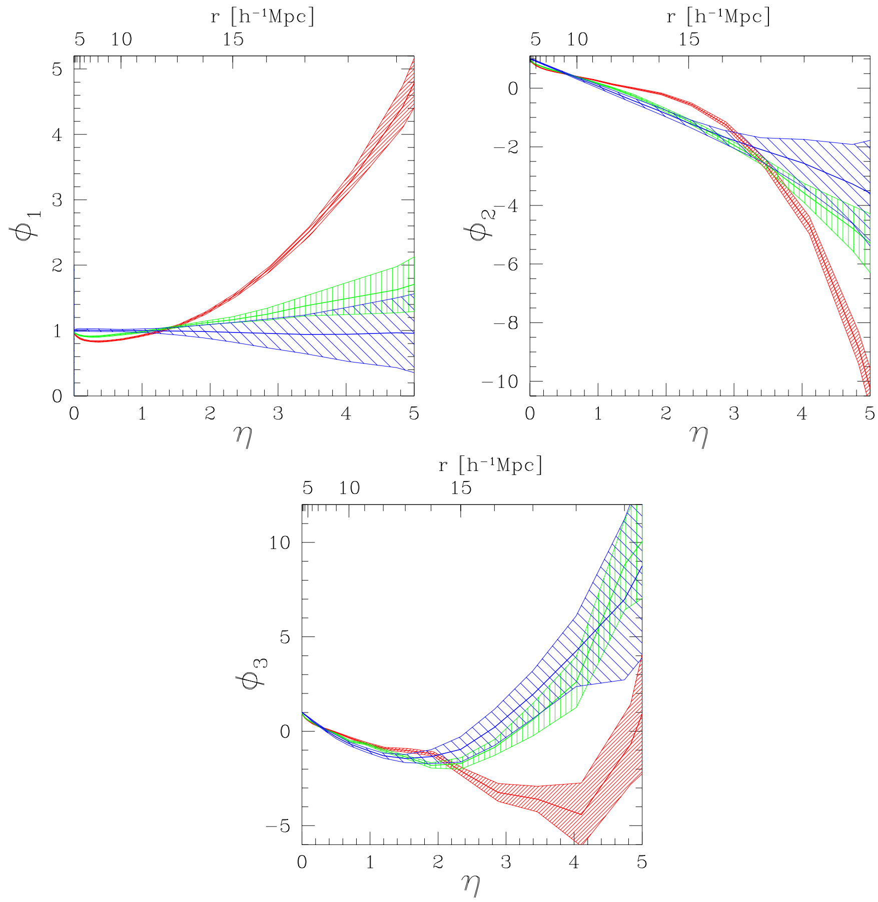

Figure 1. Minkowski functionals ϕ_μ of a volume limited sample with $100h^{-1}$Mpc depth; the dark shaded areas represent the southern part, the medium shaded the northern part, and the light shaded a Poisson process with the same number density. The shaded areas are the 1σ errors as explained in the text.

In Figure 1 we show the Minkowski functionals of the southern and northern parts together with the functionals of a Poisson process with the same number density. The northern part contains 352 galaxies, and the southern part 358 galaxies. Thus, the sample shows only small fluctuations in the number density. The errors of the Poisson process were calculated using twenty different realizations. To estimate the error of the data we calculated the Minkowski functionals of twenty subsamples 90% of the galaxies, randomly chosen from the volume limited subsample (in Kerscher et al. [6] we discuss error estimates and selection effects in detail).

In both parts of the 1.2 Jy catalogue the galaxies cluster on scales up to $10h^{-1}$Mpc significantly stronger than in the case of a Poisson process resulting in the lowered surface functional ϕ_1, integral mean curvature functional ϕ_2 and the Euler characteristic functional ϕ_3. Moreover, we realize that the northern and southern parts differ significantly. The northern part shows less clustering. Probably the most conspicuous features are the enhanced surface area ϕ_1 in the southern part on scales from 12 to 20 h^{-1}Mpc and the kink in the integral mean curvature ϕ_2 at 14 h^{-1}Mpc. This indicates that dense substructures in the southern part fill up at this scale (i.e. the balls in these substructures overlap leaving no holes). This is probably the signature of the Perseus–Pisces supercluster. On scales from 15 to 20 h^{-1}Mpc ϕ_2 is negative indicating concave structures. In the southern part the Euler characteristic is still negative in this range, therefore, the structure is dominated by interconnected tunnels (negative contributions to the Euler characteristic) and not by completely enclosed voids (positive contributions).

4. Discussion and conclusions

Recently, there have been several contradicting claims that the distribution of galaxies in the Universe is homogeneous (see e.g. Davies [7]) or fractal (see e.g. the article by Pietronero in this volume). We recall the mathematical definition of statistical homogeneity (see e.g. [11]):

For point processes the *almost–sure–homogeneity* is defined as the stationarity of the distribution of the point process under translations, i.e. the statistical properties calculated from an ensemble of realizations must not change under translations of the points. Isotropy is the stationarity of the distribution under rotations. In looking at only one realization we are not able to make statements about the statistical homogeneity. A statistically homogeneous point process may show large fluctuations in statistical quantities estimated from finite volumes in one realization. Fluctuations on the same length scale as the sample or even larger will not be detected. According to this definition certain fractal distributions are statistically homogeneous.

The volume limited subsamples we look at show fluctuations in the number density of galaxies of less than 1%. Recently Davis [7] used the whole galaxy catalogue with flux limit 1.2 Jy, but no volume limitation, and looked at galaxies in different redshift intervals, projected onto the sphere. He found strong anisotropies in the number density in the nearby region, but less in the regions further apart. Except from the subjective judgement made by examining the sample by eye, the quantitative argument is based on the number density only. In looking at the flux limited sample in the whole redshift range we find a difference of 15% in the number density between northern and southern part; the northern part incorporates 2848 galaxies, the southern part only 2465. But this may be attributed to luminosity effects. Another test on fluctuations of the number density in the flux limited 1.2 Jy catalogue is used in Kaiser et al. [5]. With statistics like σ^2, the correlation function, the power spectrum, or the correlation integral one estimates the two–point distribution only. Already here, both parts differ (see [6]). The discrepancies between north and south are enhanced by taking into account higher moments. Indeed correlations of arbitrary order enter into the Minkowski functionals [8] which reveal significant differences (see Figure 1).

Since almost identical selection effects in northern and southern parts together with the fact that the number densities of the galaxies in the volume limited subsamples analyzed are almost equal in both parts, we can draw the following conclusion:

A significant departure from a Poisson process and different clustering properties in the northern and the southern parts are detected on the scale of $200h^{-1}$Mpc (the diameter of the volume limited sample with depth of $100h^{-1}$Mpc). As shown in [6] the detected differences are less significant, but do not disappear on the scale of $400h^{-1}$Mpc. Similar anisotropies have already been reported by Rowan–Robinson et al. [10] in looking at the two–dimensional distribution of IRAS galaxies around the northern and southern galactic pole. Recently, Yess et al. [12] find indications for structures which percolate the whole sample of the 1.2 Jy catalogue.

One interpretation of the discrepancies described above could be based on the following reasoning: we assume that both the northern and the southern parts are typical for our Universe, i.e. our position does not entail any peculiarity compared with other randomly chosen positions. Then, this means that the (ensemble) variance of the statistics applied to the 1.2 Jy galaxy catalogue is at least of the order of the difference between the results for the northern and southern parts. In other words the process of large scale structure admits large fluctuations in the clustering properties on scales of $200h^{-1}$Mpc. The physical objects causing these fluctuations may be superclusters [1] or superlarge–scale structures [2]. Another interpretation in terms of a fractal distribution of galaxies is advocated by Pietronero and coworkers (see e.g. their articles in this volume).

The fluctuations detected on scales up to $200h^{-1}$Mpc (see Figure 1) imply that cosmological simulations which *enforce* homogeneity on the scale of a few hundreds of h^{-1}Mpc and suppress fluctuations on larger scales by using periodic boundary conditions cannot reproduce the large–scale fluctuations indicated by the present analysis of the 1.2 Jy catalogue, this is confirmed in [6] by comparison with a simulation.

It remains an open question, whether it is possible to explain these observed fluctuations in the clustering properties on scales up to $200h^{-1}$Mpc with linear theory and with the usual COBE normalized Gaussian initial density fields.

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