Comparison of the Large Scale Clustering in the APM and the EDSGC Galaxy Surveys

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ABSTRACT

Clustering statistics are compared in the Automatic Plate Machine (APM) and the Edinburgh/Durham Southern Galaxy Catalogue (EDSGC) angular galaxy surveys. Both surveys were independently constructed from scans of the same adjacent UK IIIa–J Schmidt photographic plates with the APM and COSMOS microdensitometers, respectively. The comparison of these catalogs is a rare practical opportunity to study systematic errors, which cannot be achieved via simulations or theoretical methods. On intermediate scales, \(0.1^\circ < \theta < 0.5^\circ\), we find good agreement for the cumulants or reduced moments of counts in cells up to sixth order. On larger scales there is a small disagreement due to edge effects in the EDSGC, which covers a smaller area. On smaller scales, we find a significant disagreement that can only be attributed to differences in the construction of the surveys, most likely the dissimilar deblending of crowded fields. The overall agreement of the APM and EDSGC is encouraging, and shows that the results for intermediate scales should be fairly robust. On the other hand, the systematic deviations found at small scales are significant in a regime, where comparison with theory and simulations is possible. This is an important fact to bear in mind when planning the construction of future digitized galaxy catalogs.

Key words: large scale structure of the universe — methods: numerical

1 INTRODUCTION

Clustering measurements from galaxy catalogues have become an important tool to test models of structure formation. Large sophisticated data sets are currently under analysis or construction. To interpret high precision measurements of clustering, a detailed understanding of the uncertainties is required. Errors can arise from finite size and geometry of the catalog, such as discreteness, edge, and finite volume effects ("cosmic errors"), from the insufficient sampling of the measurement technique itself ("measurement errors"), and finally, "systematic errors" arise from data reduction, object detection, magnitude uncertainties, etc. Studying the first two classes is by no means simple, but theoretical methods (e.g., Szapudi & Colombi 1996, hereafter SC96) and N-body simulations yield reasonable estimates. Systematic errors are even more difficult to investigate, and a unique opportunity is provided, when the same raw data are reduced independently by two research teams. The goal of this Letter is to seize on such an opportunity: the APM and the EDSGC galaxy surveys were constructed independently from the same underlying photographic plates. In particular, we investigate the degree of reproducibility of the higher order clustering measurements, i.e. to what extent different choices during the construction of a galaxy catalog can lead to different estimates of clustering.

The most widespread tools to study clustering in a galaxy catalog are the two-point correlation function, \(\xi_2\), and the amplitudes of the higher order correlation functions. These latter are usually expressed in the form of hierarchical ratios: \(S_J = \xi_J/\xi_2^{J-1}\), where \(\xi_J\) is the \(J\)-order correlation function or reduced cumulant. The predictions for \(S_J\)’s in both perturbation theory and N-body simulations (Peebles 1980; Bernardeau 1992; Juszkiewicz, Bouchet, & Colombi 1993; Bernardeau 1994; Gaztañaga & Baugh 1995; Baugh, Gaztañaga, & Efstathiou 1995, hereafter BGE94; Colombi et al. 1996; Baugh & Gaztañaga, 1996; Szapudi, Quinn, Stadel, & Lake 1997) can be used to test the gravitational instability picture, the form of the initial conditions and the biasing parameters (Frieman & Gaztañaga 1994; Gaztañaga & Frieman 1994, hereafter GF94). The \(S_J\)’s are more difficult to measure and interpret than the two-point function, however, at low orders, they are less affected by intrinsic observational uncertainties, like time evolution or projection effects.

In section 2 we summarize the properties of the two catalogues, the method of analysis and the actual compar-
2 THE APM AND EDINBURGH/DURHAM SOUTHERN GALAXY CATALOGUES

The APM Galaxy Survey covers 4300 square degrees on the sky and contains over 2 million galaxies to a limiting apparent magnitude of $b_J \leq 20.5$ (Maddox et al. 1990a; Maddox et al. 1990b; Maddox et al. 1990c; Maddox et al. 1996). It was constructed from APM (a microdensitometer) scans of 188 adjacent UK IIIa–J Schmidt photographic plates and reaches a limiting magnitude of $b_J = 20.5$. In an extensive analysis of the systematic errors involved in plate matching, Maddox et al. (1996) have placed an upper limit of $\delta w(\theta) \sim 1 \times 10^{-3}$ on the likely contribution of the systematic errors to the angular correlations. The shape of the angular correlation function measured from the survey at scales of $\theta > 1^\circ$ indicates that the universe contains more structure on large scales than is predicted by the standard Cold Dark Matter scenario (Maddox et al. 1990c). The higher order correlations in the APM were measured by (Gaztañaga 1994, hereafter G94; Szapudi et al. 1995, hereafter SDES; Szapudi & Szalay 1997a).

The EDSGC is a catalogue of 1.5 million galaxies covering $\approx 1000$ square degrees centered on the Southern Galactic Pole. The database was constructed from COSMOS scans (a microdensitometer) of 60 adjacent UK IIIa–J Schmidt photographic plates (a subset of the APM plates) and also reaches a limiting magnitude of $b_J^{\text{EDSGC}} = 20.5$.

The entire catalogue has $< 10\%$ stellar contamination and is $\gtrsim 95\%$ complete for galaxies brighter than $b_J = 19.5$ (Heydon-Dumbleton et al. 1989). The two-point galaxy angular correlation function measured from the EDSGC has been presented by Collins, Nichol, & Lumsden (1992) and Nichol & Collins (1994). The higher order correlations in the EDSGC were measured by Szapudi, Meiksin, & Nichol 1996, hereafter SMN96.

We emphasize that the raw data for both catalogs comprise of the same UK IIIa–J Schmidt Plates (a smaller subset in case of the EDSGC), while the hardware to digitize the plates and the software to classify and detect objects, measure their apparent magnitudes were different. In particular, different methods of calibration, plate-matching, deblending algorithms were employed. As a consequence, there is a small offset in the magnitude scales of the two catalogues (Nichol 1992), even though a simple one-to-one mapping can be established.

Magnitude cuts for the comparison of the statistics were determined by practical considerations. For the APM we follow G94 and use $m_{\text{APM}} = 17 - 20$, which is half a magnitude brighter than the completeness limit. For the EDSGC catalogue, which is complete to about $m_{\text{EDSGC}} = 20.3$ magnitude, we follow SMN96 to use a magnitude cut of $16.98 \leq m_{\text{EDSGC}} \leq 19.8$, which is again half a magnitude brighter than the completeness limit. Based on matching the surface densities listed in SDES, these magnitude ranges approximately correspond to each other. This facilitates the direct cross-comparison of the results.

3 THE METHOD OF ANALYSIS

The calculation of the higher order correlation functions followed closely the method outlined in (SMN96). It consists of estimating the probability distribution of counts in cells, calculation of the factorial moments, and extraction of the normalized, averaged amplitudes of the $J$-point correlation functions. For the most crucial first step the infinitely oversampling algorithm of (Szapudi 1997) was used. Only few of the most important definitions are presented below.

The average of the $J$-point angular correlation function on a scale $\ell$ is defined by

$$\bar{\omega}_J(\ell) = A(\ell)^{-J} \int d^2r_1 \cdots d^2r_J \omega_J(r_1, \ldots, r_J),$$

where $\omega_J$ is the $J$-point correlation function in the two dimensional survey, and $A(\ell)$ is the area of a square cell of size $\ell$. The hierarchical ratios, $s_J$, are defined in the usual way,

$$s_J = \frac{\bar{\omega}_J}{\bar{\omega}_2}.$$

The raw counts in cells measurements are reduced to a set consisting of $n, \bar{\omega}_2, s_J$, which forms a suitable basis for subsequent comparison of the statistics; $n$ denotes the average count in a cell.

Counts in cells were measured in square cells with sizes in the range $0.01525^\circ - 2^\circ$ (corresponding to $0.1 - 14h^{-1}\text{Mpc}$ with $D \approx 400h^{-1}\text{Mpc}$, the approximate depth of the catalogues). Practical considerations determined this scale range: the upper scale was chosen to minimize the edge effects from cut-out holes, while the smallest scale approaches that of galaxy halos for the typical depth of the catalogs. For details see (SMN96). Note that physical coordinates were used in both surveys to eliminate the effects of distortion.

4 COMPARISON

The amplitudes of the measured $J$-point correlation functions for $2 \geq J \geq 6$ are displayed on a series of figures. To facilitate comparison with perturbation theory, angular scales in all graphs were converted to an equivalent circular cell size, $\theta$, i.e. $\pi \theta^2 = \ell^2$. Note that square cells were used for the measurements, up to a small deformation due to projection. This has a negligible effect through slightly differing form factors, which cancels out anyway when comparing the results from the two catalogs with each other. The cell size in the APM pixel maps is defined by dividing the full APM area over the number of cells. The corresponding scale is about 5% smaller than previously used in G94 and SDES, where the cell size was defined as the mean equal area projection size.

The mean density of the EDSGC counts is about 10% smaller than that of the APM (see also SMN97). This is partially due to star mergers which account to 5% of the APM images in the $b_J = 17 - 20$ slice (Maddox et al. 1990). The remaining 5% can be attributed to a small difference in the depths due to a slight offset in the magnitude slices.

Figure 1 shows the variance of counts-in-cells as a function of the cell radius in degrees. The full squares linked by the solid line correspond to the measurement in the EDSGC.
Comparison of the APM and the EDSGC Surveys

Figure 1. The solid squares joined by continuous lines show our measurement of the angular $w_2$ over the EDSGC survey area with infinite sampling. Open squares with errorbars display the mean and variance of the $w_2$ measurements in four equal parts of the APM survey, estimated with low sampling. The short-dashed line corresponds to similar APM measurements with infinite sampling. The long-dashed line shows the APM results restricted to the EDSGC region measured with infinite sampling.

catalogue. The small differences in the mean depth mentioned above should produce an upward shift of about 10% in the EDSGC correlation amplitude, which is confirmed by the Figure. The open squares display the measurements by G94 for the full APM catalogue, while the short-dashed line is the recalculation of the same with infinite sampling. The long-dashed line is the measurement of a subregion of the APM which overlaps with the EDSGC ($EDSGC \cap APM$). The latter agrees well within the errors with the full APM measurements and is slightly lower than the corresponding $w_2$ in the EDSGC catalogue, roughly as expected from the mentioned differences. There is an overall agreement between all estimates, at least on large scales. On smaller scales the APM appears to produce slightly lower values; this is probably related to the larger discrepancy of the hierarchical amplitudes which will be discussed next.

Figures 2-3 compare the skewness, $s_3$, and the higher order $s_J$'s, $J = 4, 5, 6$. The following discussion is equally applicable to all orders; the separate graph for $J = 3$ shows more details. Contrary to what happened for $w_2$, a small difference in the depth should not change the hierarchical ratios, as the depth cancels out in the normalization (see Groth & Peebles 1977). The Figures follow this expectation. For scales of about 0.2° to 2° the agreement is good between the full EDSGC and the same region of the APM ($EDSGC \cap APM$ region). The increase of the $s_J$'s at the largest scales ($\theta > 0.5°$) in the $EDSGC \cap APM$ region is due to edge and finite volume effects: a similar trend appears in the same region for both catalogues. On these large scales, the full APM measurements are more accurate since its larger area decreases cosmic errors. Note that for the measurement represented with the short dashes the edges of the catalog were cut out generously to eliminate any possible inhomogeneity. In addition, the masks was fully excluded, while the original measurement followed a somewhat different procedure (see G94 for details). This could account for the slight difference at the largest scales.

The $S_J$'s measured in the $EDSGC \cap APM$ region of the APM are compatible with the errors of the full APM measurements at most scales. At scales larger than 0.5°, edge effects start to dominate the errors of the smaller sample. For $0.1° \geq \theta \geq 0.5°$ the $EDSGC \cap APM$ region appears to produce slightly lower hierarchical ratios than the full APM. These values in some cases are outside of the formal errorbars. The reason for this is that dividing the sample into subsamples is an approximate estimate of the errors, and it can lead to underestimation as the subsamples are not fully independent. Moreover, for a non-Gaussian error distribution values outside the formal errorbar are less unlikely (SC96).

At the smaller scales there is a significant statistical difference between the APM and the EDSGC. This is not due to finite volume effects, since it persists when only the same region of the sky is used. The identical geometry with the same magnitude cut excludes edge or discreteness effect as well, thus all cosmic errors. The difference is not due to the method of estimation either, since the original low sampling measurement by G94 gives similar results to the recalculation with infinite oversampling, which fully eliminates measurement errors (SC96; Szapudi 1997). The only
remaining possibility is that the results should be attributed to systematics.

5 DISCUSSION

According to SMN97, insufficient sampling can cause severe underestimation or the higher order $S_i$’s. This could be a possible cause for the disagreement between the EDGSC and the APM on scales smaller than 0.2 degrees, since the original APM measurements by G94 were performed on density pixel map with resolution given by the lowest scale shown at the figure. However, the infinite sampling $S_i$’s are in good agreement with the original analysis by G94. Although, as expected, the infinite oversampling results at small scales seem slightly higher than the corresponding low sampling ones, the Figures prove that this effect is not significant and it can be discounted as the main reason for the disagreement between the APM and the EDSCG. The discrepancies on small scales are therefore due to intrinsic differences in the catalogues. Since both catalogs use same raw photographic plates, the difference discovered with the same statistical methods must lie with the different choices of hardware and software during the scans and/or the data reduction. The dissimilarity in the deblending algorithms is a particularly good candidate to account for the detected statistical difference (G. Efstathiou, private communication). However, this point needs further investigation.

Previous results and their interpretations on large scales seem unaffected by the detected discrepancies. In particular, both the APM and the EDSCG higher order correlations are in general agreement with perturbation theory (G94, GF94, BGE95, SMN97). In summary, the results support qualitatively scenarios with gravitational instability arising from Gaussian initial conditions, with little or no biasing. Note that the EDSCG barely probes quasi-linear scales ($R > 5h^{-1}\text{Mpc}$ or $\theta > 1'$), thus extended perturbation theory, and results from $N$-body simulations have to be invoked as a theoretical basis for comparison at smaller scales. There is hint that, at least qualitatively, the EDSCG results at the smallest scales follow $N$-body simulations more closely, while the drop experienced in the APM reduced moments at the same scales is unexpected, and could be an artificial effect. The new generation of CCD based red-shift and angular surveys, such as the SDSS, and 2DF, should be able to clarify this situation and put tighter constraints on biasing models.

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Figure 3. Same as in Figure 2 for $s_4$, $s_5$ and $s_6$. 