THE RICHNESS-DEPENDENT CLUSTER CORRELATION FUNCTION: EARLY SLOAN DIGITAL SKY SURVEY DATA

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ABSTRACT

The cluster correlation function and its richness dependence are determined from 1108 clusters of galaxies—the largest sample of clusters studied so far—found in 379 deg$^2$ of Sloan Digital Sky Survey early data. The results are compared with previous samples of optically and X-ray–selected clusters. The richness-dependent correlation function increases monotonically from an average correlation scale of $\approx 12 h^{-1}$ Mpc for poor clusters to $\approx 25 h^{-1}$ Mpc for the richer, more massive clusters with a mean separation of $\approx 90 h^{-1}$ Mpc. X-ray–selected clusters suggest slightly stronger correlations than optically selected clusters ($\approx 2\sigma$). The results are compared with large-scale cosmological simulations. The observed richness-dependent cluster correlation function is well represented by the standard flat $\Lambda$-dominated cold dark matter (LCDM) model ($\Omega_m \approx 0.3$, $h \approx 0.7$) and is inconsistent with the considerably weaker correlations predicted by $\Omega_m = 1$ models. An analytic relation for the correlation scale versus cluster mean separation, $r_0 - d$, that best describes the observations and the LCDM prediction is $r_0 \approx 2.6 \sqrt{d}$ (for $d \approx 20 - 90 h^{-1}$ Mpc). Data from the complete Sloan Digital Sky Survey, when available, will greatly enhance the accuracy of the results and allow a more precise determination of cosmological parameters.

Subject headings: cosmological parameters — cosmology: observations — cosmology: theory — dark matter — galaxies: clusters: general — large-scale structure of universe

1. INTRODUCTION

The spatial correlation function of clusters of galaxies and its richness dependence provide powerful tests of cosmological models: both the amplitude of the correlation function and its dependence on cluster mass/richness are determined by the underlying cosmology. It has long been shown that clusters are more strongly correlated in space than galaxies, by an order of magnitude; the typical galaxy correlation scale, $\approx 5 h^{-1}$ Mpc, increases to $\approx 20 - 25 h^{-1}$ Mpc for the richest clusters (Bahcall & Soneira 1983; Klypin & Kopylov 1983; see also Bahcall 1988; Huchra et al. 1990; Postman, Huchra, & Geller 1992; Bahcall & West 1992; Peacock & West 1992; Dalton et al. 1994; Croft et al. 1997; Abadi, Lambas, & Muriel 1998; Lee & Park 1999; Borgani, Plionis, & Kolokotronis 1999; Collins et al. 2000; Gonzalez, Zaritsky, & Wechsler 2002 and references therein). Bahcall & Soneira (1983) showed that the cluster correlation function is richness-dependent: the correlation strength increases with cluster richness, or mass. Many observations have since confirmed these results (references above), and theory has nicely explained them (Kaiser 1984; Bahcall & Cen 1992; Mo & White 1996; Governato et al. 1999; Colberg et al. 2000; Moscardini et al. 2000; Sheth, Mo, & Tormen 2001). However, the uncertainties in the observed cluster correlation function as manifested by the scatter among different measurements remain large.

In this paper we use the largest sample of clusters yet investigated, 1108 clusters selected from 379 deg$^2$ of early Sloan Digital Sky Survey data (see the SDSS cluster catalog; Bahcall et al. 2003b), to determine the cluster correlation function. This large, complete sample of objectively selected clusters, ranging from poor to moderately rich systems in the redshift range $z = 0.1 - 0.3$, allows a new determination of the cluster correlation function and its richness dependence. We compare the SDSS cluster correlation function with results of previous optically and X-ray–selected clusters (§ 3). We use large-scale cosmological simulations to compare the observational results with cosmological models (§ 4). The data are consistent with predictions from the standard flat $\Lambda$-dominated cold dark matter (LCDM) model ($\Omega_m \approx 0.3$, $h \approx 0.7$), which best fits numerous other observations (e.g., Bahcall et al. 1999; Bennett et al. 2003; Spergel et al. 2003).

2. SDSS CLUSTER SELECTION

The SDSS (York et al. 2000) will provide a comprehensive digital imaging survey of $10^4$ deg$^2$ of the north Galactic cap (and a smaller, deeper area in the south) in five bands ($u, g, r, i, z$) to a limiting magnitude of $r < 23$, followed by a spectroscopic multifiber survey of the brightest 1 million galaxies, to $r < 17.7$, with a median redshift of $z \approx 0.1$ (Fukugita et al. 1996; Gunn et al. 1998; Lupton et al. 2001; Hogg et al. 2001; Strauss et al. 2002). For more details of the SDSS, see Smith et al. (2002), Stoughton et al. (2002), and Pier et al. (2003).

Cluster selection was performed on 379 deg$^2$ of SDSS commissioning data, covering the areas of $\alpha(J2000.0) = 355^\circ$ to $56^\circ$ and $145^\circ$ to $236^\circ$ at $\delta(J2000.0) = -1^\circ$ to $1^\circ$ (runs 94/125 and 752/756). The clusters studied here were selected from these imaging data using a color-magnitude maximum likelihood brightest cluster galaxy method (maxBCG; J. Annis et al. 2004, in preparation). The clusters are described in the SDSS cluster catalog of...
Bahcall et al. (2003b). The maxBCG method selects clusters based on the well-known color-luminosity relation of the BCG and the E/S0 red ridgeline. The method provides a cluster richness estimate, \( N_{\text{gal}} \) [the number of E/S0 galaxies within 1 \( h^{-1} \text{Mpc} \) of the BCG that are fainter than the BCG and brighter than \( M_i(\text{lim}) = -20.25 \)], and a cluster redshift estimate that maximizes the cluster likelihood (with 1 \( \sigma \) uncertainty of \( \sigma_z = 0.014 \) for \( N_{\text{gal}} \geq 10 \) and \( \sigma_z = 0.01 \) for \( N_{\text{gal}} \geq 20 \) clusters). We use all maxBCG clusters in the estimated redshift range \( z_{\text{est}} = 0.1 - 0.3 \) that are above a richness threshold of \( N_{\text{gal}} \geq 10 \) (corresponding to a velocity dispersion \( \gtrsim 350 \text{ km s}^{-1} \)); the sample contains 1108 clusters. The selection function and false-positive detection rate for these clusters have been estimated from simulations and from visual inspection to be \( \lesssim 10\% \) (Bahcall et al. 2003b).

3. THE CLUSTER CORRELATION FUNCTION

The two-point spatial correlation function is determined by comparing the observed distribution of cluster pairs as a function of pair separation with the distribution of random catalogs in the same volume. The correlation function is estimated from the relation \( \xi_{\text{cc}}(r) = F_{\text{DD}}(r)/F_{\text{RR}}(r) - 1 \), where \( F_{\text{DD}}(r) \) and \( F_{\text{RR}}(r) \) are the frequencies of cluster-cluster pairs as a function of pair separation \( r \) in the data and in random catalogs, respectively. The random catalogs contain \( \sim 10^3 \) times the number of clusters in each data sample; the clusters are randomly positioned on the sky within the surveyed area. The redshifts of the random clusters follow the redshifts of the observed clusters in order to minimize possible selection effects with redshift. Comoving coordinates in a flat LCDM cosmology with \( \Omega_m = 0.3 \) and a Hubble constant of \( H_0 = 100 \text{ h km s}^{-1} \text{ Mpc}^{-1} \) are used throughout.

The uncertainty in the estimated cluster redshifts (\( \sigma_z = 0.01 \) for \( N_{\text{gal}} \geq 20 \) clusters and \( \sigma_z = 0.014 \) for \( N_{\text{gal}} \geq 10 \) to \( \geq 15 \) clusters; \( \lesssim 2 \)) causes a small smearing effect in the cluster correlations. We use Monte Carlo simulations to correct for this effect. We use simulations with a realistic cluster distribution with redshift and richness, convolve the clusters with the observed Gaussian scatter in redshift as

![Figure 1](image_url)
given above, and determine the new convolved cluster correlation function. As expected, the redshift uncertainty causes a slight weakening of the true correlation function, especially at small separations, because of the smearing effect of the redshift uncertainty. We determine the correction factor for this effect as a function of scale \( r \) from \( 10^2 \) Monte Carlo simulations for each sample. The correction factor (typically \( \lesssim 20\% \)) is then applied to the correlation function. An additional small correction factor due to false-positive detections is also determined from Monte Carlo simulations using the estimated false-positive detection rate of \( 10\% \pm 5\% \) for \( N_{\text{gal}} \geq 10 \) clusters, \( 5\% \pm 5\% \) for \( N_{\text{gal}} \geq 13 \), and less than \( 5\% \) for the richest clusters with \( N_{\text{gal}} \geq 15 \). The correlation function uncertainties are determined from the Monte Carlo simulations. Each simulation contains the same number of clusters as the relevant data sample. The final uncertainties include the statistical uncertainties and the uncertainties due to the small correction factors in the redshift and false-positive corrections.

The correlation function is determined for clusters with richness thresholds of \( N_{\text{gal}} \geq 10, 13, 15, \) and \( \geq 20 \). The space densities of these clusters, corrected for selection function and redshift uncertainty (Bahcall et al. 2003a), are \( 5.3 \times 10^{-5}, 2.2 \times 10^{-5}, 1.4 \times 10^{-5}, \) and \( 0.5 \times 10^{-5} \ h^3 \text{Mpc}^{-3} \) (\( \xi 0.1 - 0.3 \)). The correlation functions of the four samples are presented in Figure 1 and Table 1. The best-fit power-law relation, \( \xi(r) = (r/r_0)^{-\gamma} \), derived for \( r \leq 50 \ h^{-1} \) Mpc, is shown for each sample. The power-law slope \( \gamma \) has been treated as both a free parameter and a fixed value (\( \gamma = 2 \)). The difference in the correlation scale \( r_0 \) for these different slopes is small (\( \lesssim 2\% \)), well within the measured uncertainty.

The richness dependence of the cluster correlation function is shown in Figure 2; it is presented as the dependence of the correlation scale \( r_0 \) on the cluster mean separation \( d \) (Bahcall \& Soneira 1983; Szalay \& Schramm 1985; Bahcall 1988; Croft et al. 1997; Governato et al. 1999; Colberg et al. 2000). Samples with intrinsically larger mean separations correspond to lower intrinsic cluster abundances \( (n_d = d^{-3}) \) and thus to higher cluster richness and mass (for complete samples). We compare our results with those of previous optically and X-ray–selected cluster samples (Fig. 2). These

### Table 1: The Cluster Correlation Function

| Sample | \( N_{\text{gal}} \geq 10 \) | \( z \) | \( \gamma \) | \( r_0 \) (Mpc) | \( d \) (Mpc) | References |
|--------|-----------------|-----|-----|------|-------|----------|
| SDSS   | \( N_{\text{gal}} \geq 10 \) | 1108 | 0.1–0.3 | 2     | 12.7 ± 0.6 | 26.6     |
| N_{\text{gal}} \geq 13 | 472 | 0.1–0.3 | 2     | 15.1 ± 0.9 | 35.6 |
| N_{\text{gal}} \geq 15 | 300 | 0.1–0.3 | 2     | 17.3 ± 1.3 | 41.5 |
| N_{\text{gal}} \geq 20 | 110 | 0.1–0.3 | 2     | 21.2 ± 2.8 | 58.1 |
| Abell  | \( R \geq 1 \) | 195 | \( \lesssim 0.08 \) | 2     | 21.1 ± 1.3 | 52   |
| APM    | \( R \geq 50 \) | 364 | \( \sim 0.1 \) | 2.1   | 14.2 ± 0.4 | 30   |
| N_{\text{gal}} \geq 13 | 114 | \( 0.1 \) | 2.1   | 16.6 ± 1.3 | 48   |
| N_{\text{gal}} \geq 15 | 110 | \( 0.1 \) | 1.7   | 18.4 ± 2.1 | 57   |
| N_{\text{gal}} \geq 20 | 58 | \( 0.1 \) | 2.3   | 22.2 ± 2.8 | 69   |
| [2]    | [23.0 ± 2.9] | 29 | \( 0.1 \) | 2.8   | 18.4 ± 4.8 | 79   |
| [2]    | [22.6 ± 6.0] | 17 | \( 0.1 \) | 3.2   | 21.3 ± 5.3 | 86   |
| R_{\text{gal}} \geq 110 | 17 | \( 0.1 \) | 2     | 16.2 ± 2.3 | 41   |
| EDCC   | \( R \geq 0.13 \) | 79  | \( \lesssim 0.13 \) | 2     | 16.2 ± 2.3 | 41   |
| LCDDCS | 178 | 0.35–0.475 | 2.15 | 14.7 ± 2.8 | 38.4 |
| 158 | 0.35–0.525 | 2.15 | 17.2 ± 2.8 | 46.3 |
| 115 | 0.35–0.575 | 2.15 | 20.9 ± 3.6 | 58.1 |
| REFLEX | \( L_X \geq 0.08 \) | 39  | \( \lesssim 0.05 \) | 2     | 24.8 ± 2.5 | 48   |
| \( L_X \geq 0.18 \) | 84  | \( \lesssim 0.075 \) | 2     | 25.8 ± 1.9 | 61   |
| \( L_X \geq 0.3 \) | 108 | \( \lesssim 0.10 \) | 2     | 31.3 ± 2.3 | 72   |
| \( L_X \geq 0.5 \) | 101 | \( \lesssim 0.125 \) | 2     | 25.8 ± 3.3 | 88   |
| XBACS  | \( L_X \geq 0.24 \) | 49  | \( \lesssim 0.07 \) | 1.8–2.5 | 25.7 ± 3.7 | 66   |
| \( L_X \geq 0.48 \) | 67  | \( \lesssim 0.09 \) | 1.8–2.5 | 25.2 ± 4.1 | 82   |
| \( L_X \geq 0.65 \) | 59  | \( \lesssim 0.11 \) | 1.6–2.2 | 30.3 ± 1.8 | 98   |
| Groups | \( M_r \geq 5E+13 \) | 920 | \( 0.12 \) | 2     | 11.7 ± 0.6 | 20.9 |
| \( M_r \geq 1E+14 \) | 540 | \( 0.13 \) | 2     | 13.4 ± 0.9 | 28.9 |

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\( a \) Sample and subsample threshold in richness, X-ray luminosity \( (10^{44} \text{ergs s}^{-1}) \), or \( M_{\text{gal}} \) \( (M_\odot) \). The SDSS, LCDCCS, and groups use LCDM cosmology for their \( r_0 \) and \( d \); all others use \( \Omega_{\text{m}} = 1 \). All scales are for \( h = 1 \).

\( b \) Correlation-scale \( r_0 \) using a slope of 2 (see §3).

References.—(1) Bahcall \& Soneira 1983; (2) Peacock \& West 1992; (3) Croft et al. 1997 (larger \( r_0 \) values are obtained for APM by Lee \& Park 1999); (4) Nichol et al. 1992; (5) Gonzalez et al. 2002; (6) Collins et al. 2000; (7) Lee \& Park 1999; see also (8) Abadi et al. 1998; (9) Zandivarez et al. 2003.
include the correlation function of Abell clusters (richness class $\geq 1$ [Bahcall & Soneira 1983; Peacock & West 1992]; richness $= 0$ clusters are an incomplete sample and should not be included); Automatic Plate Measuring Facility (APM) clusters (Croft et al. 1997); Edinburgh-Durham clusters (EDCC; Nichol et al. 1992); the Las Campanas Distant Cluster Survey (LCDCS; Gonzalez et al. 2002); galaxy groups (Two-Degree Field; Zandivarez, Merchan, & Padilla 2003); and X-ray–selected clusters (REFLEX: Collins et al. 2000; XBACS: Abadi et al. 1998; Lee & Park 1999). A summary of the results is presented in Table 1. For proper comparison of different samples, we use the same set of standard parameters in the relative $r_0$-$d$ plot: redshift $z \sim 0$, correlation power-law slope $\gamma = 2$, and all scales in comoving units in the LCDM cosmology. We discuss these below.

Most of the cluster samples are at small redshifts, $z \lesssim 0.1$ (Table 1). The only exceptions are the SDSS
clusters \((z \approx 0.1–0.3)\) and the LCDCS \((z \approx 0.35–0.575)\).

To convert the results to \(z \approx 0\), we use large-scale cosmological simulations of an LCDM model and determine the cluster correlation function and the \(r_0-d\) relation at different redshifts. Details of the simulations and cluster selection are given in Bode et al. (2001; see also § 4). The correlation function is determined following the same method used for the data. We find that while both \(r_0\) and \(d\) increase with redshift for the same mass clusters, as expected, there is no significant change \((\lesssim 3\%)\) in the \(r_0-d\) relation as the redshift changes from \(z = 0\) to \(\sim 0.5\) (for \(d \sim 20–90 \text{ h}^{-1} \text{ Mpc}\)). In Figure 2 we plot the individual parameters \(r_0\) and \(d\) at the sample’s measured redshift as listed in Table 1; the relative \(r_0-d\) relation remains essentially unchanged to \(z \approx 0\).

Most of the cluster correlation functions (Table 1) have a power-law slope in the range of \(\sim 2 \pm 0.2\). The APM highest richness subsamples report steeper slopes \((3.2, 2.8, 2.3)\); they also have the smallest number of clusters \((17, 29, 58)\). The correlation scale \(r_0\) is inversely correlated with the power-law slope; a steeper slope typically yields a smaller correlation scale. We use the APM best \(\chi^2\) fit for \(r_0\) at \(\gamma = 2\) (Croft et al. 1997) for these richest subsamples. Using cosmological simulations, we investigate the dependence of \(r_0\) on the slope within the same observed range of \(2 \pm 0.2\). For the current range of mean separations \(d\), we find only a small change in \(r_0\) \((\lesssim 5\%)\) when the slope changes within this observed range. The X-ray cluster sample XBACS yields similar correlation scales for slopes ranging from \(\sim 1.8\) to \(2.5\) (Abadi et al. 1998; Lee & Park 1999). Similarly, the SDSS correlation scales are essentially the same when using a free slope fit (typically 1.7–2.1) or a fixed slope of 2. Since most of the observations are reported with a slope of 2, we adopt the latter as the standard slope for the results presented in Figure 2. The only correction applied is to the three highest richness APM subsamples; these are shown both with and without the correction. We also verify using cosmological simulations that the LCDCS sample at \(z \sim 0.35–0.575\), with a slope of 2.15, has an \(r_0-d\) relation consistent with the standard set of parameters used in Figure 2 \((z \approx 0, \gamma \approx 2)\).

Finally, we convert all scales \((r_0\) and \(d\) from Table 1\) to the same \(\Omega_m = 0.3\) cosmology (LCDM). The effect of the cosmology on the observed \(r_0-d\) relation is small \((\lesssim 3\%)\), partly because of the small redshifts, for which the effect is small, but also because the cosmology affects both \(r_0\) and \(d\) in the same way, thus minimizing the relative change in the \(r_0-d\) relation.

A comparison of all the results, including the minor corrections discussed above, is shown in Figure 2. Figure 2 \((\text{top})\) presents both optically and X-ray–selected clusters; Figure 2 \((\text{bottom})\) includes only the optical samples. The richness dependence of the cluster correlation function is apparent in Figure 2. The X-ray clusters suggest somewhat stronger correlations than the optical clusters, at a \(\sim 2\ \sigma\) level. Improved optical and X-ray samples should reduce the scatter and help address this important comparison.

4. COMPARISON WITH COSMOLOGICAL SIMULATIONS

We compare the results with large-scale cosmological simulations of an LCDM model \((\Omega_m = 0.3, \ h = 0.67, \ \sigma_8 = 0.9)\) and a tilted standard CDM model (TSCDM; \(\Omega_m = 1, \ h = 0.5, \ n = 0.625, \ \sigma_8 = 0.5)\). The tree-particle-mesh high-resolution large-volume simulations (Bode et al. 2001) used \(1.34 \times 10^8\) particles with an individual particle mass of \(6.2 \times 10^{11} \text{ h}^{-1} M_{\odot}\); the periodic box size is \(1000 \text{ h}^{-1} \text{ Mpc}\) for LCDM and \(669 \text{ h}^{-1} \text{ Mpc}\) for TSCDM. The simulated clusters are ordered by their abundance based on cluster mass within \(1.5 \text{ h}^{-1} \text{ Mpc}\). The results of the cosmological simulations for the \(r_0-d\) relation of \(z = 0\) clusters are presented by the two bands in Figure 2 \((1 \sigma \text{ range})\). A correlation function slope of 2 was used in the analysis. We also show the simulation results of Colberg et al. (2000) for LCDM and Governato et al. (1999) for a standard untilted SCDM \((\Omega_m = 1, \ h = 0.5, \ n = 1, \ \sigma_8 = 0.7)\). The agreement among the simulations is excellent. As expected, the untilted SCDM model yields smaller \(r_0\) values than the strongly tilted model; LCDM yields the strongest correlations.

We determine an analytic relation that approximates the observed and the LCDM \(r_0-d\) relation: \(r_0 \approx 2.6\sqrt{d}\) \((\text{for } 20 \leq d \leq 90; \text{ all scales are in } \text{h}^{-1} \text{ Mpc})\). The observed richness-dependent cluster correlation function agrees well with the standard LCDM model. The correlation scales, and the \(r_0-d\) relation, increase as \(\Omega_m h\) decreases, and the spectrum shifts to larger scales. The \(\Omega_m = 1\) models yield considerably weaker correlations than observed. This fact has of course been demonstrated earlier; in fact, the strength of the cluster correlation function and its richness dependence were among the first indications against the standard LCDM and Governato et al. (1999) for a standard untilted SCDM \((\Omega_m = 1, \ h = 0.5)\). The agreement among the simulations is excellent. As expected, the untilted SCDM model yields smaller \(r_0\) values than the strongly tilted model; LCDM yields the strongest correlations.

5. CONCLUSIONS

We determine the cluster correlation function and its richness dependence using 1108 clusters of galaxies found in 379 deg\(^2\) of early SDSS data. The cluster correlation function shows a clear richness dependence, with increasing correlation strength with cluster richness/mass. The results are combined with previous samples of optical and X-ray clusters and compared with cosmological simulations. We find that the richness-dependent cluster correlation function is consistent with predictions from the standard flat LCDM model \((\Omega_m = 0.3, \ h = 0.7)\) and, as expected, inconsistent with the weaker correlations predicted by \(\Omega_m = 1\) models. We derive an analytic relation for the correlation scale versus cluster mean separation relation that best describes the observations and the LCDM expectations: \(r_0 \approx 2.6\sqrt{d}\). X-ray–selected clusters suggest somewhat stronger correlations than the optically selected clusters, at a \(\sim 2\ \sigma\) level.

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REFERENCES

Abadi, M., Lambas, D., & Muriel, H. 1998, ApJ, 507, 526
Bahcall, N. A. 1988, ARA&A, 26, 631
Bahcall, N. A., & Cen, R. 1992, ApJ, 398, L81
Bahcall, N. A., Ostriker, J. P., Perlmutter, S., & Steinhardt, P. J. 1999, Science, 284, 1481
Bahcall, N. A., & Soneira, R. M. 1983, ApJ, 270, 20
Bahcall, N. A., & West, M. J. 1992, ApJ, 392, 419
Bahcall, N. A., et al. 2003a, ApJ, 585, 182
———. 2003b, ApJS, 148, 243
Bennett, C. L., et al. 2003, ApJS, 148, 1
Bode, P., Bahcall, N. A., Ford, E. B., & Ostriker, J. P., 2001, ApJ, 551, 15
Borgani, S., Plionis, M., & Kolokotronis, V. 1999, MNRAS, 305, 866
Colberg, J. M., et al. 2000, MNRAS, 319, 209
Collins, C., et al. 2000, MNRAS, 319, 939
Croft, R. A. C., et al. 1997, MNRAS, 291, 305
Dalton, G. B., et al. 1994, MNRAS, 271, L47
Fukugita, M., et al. 1996, AJ, 111, 1748
Gonzalez, A. H., Zaritsky, D., & Wechsler, R. H. 2002, ApJ, 571, 129
Governato, F., et al. 1999, MNRAS, 307, 949
Gunn, J. E., et al. 1998, AJ, 116, 3040
Hogg, D. W., et al. 2001, AJ, 122, 2129
Huchra, J., Henry, J. P., Postman, M., & Geller, M. 1990, ApJ, 365, 66
Kaiser, N. 1984, ApJ, 284, L9
Klypin, A. A., & Kopylov, A. I. 1983, Soviet Astron. Lett., 9, 41
Lee, S., & Park, C. 1999, J. Korean Astron. Soc., 32, 1
Lupton, R., et al. 2001, in ASP Conf. Ser. 238, Astronomical Data Analysis Software and Systems X, ed. F. R. Harnden, Jr., F. A. Primini, & H. E. Payne (San Francisco: ASP), 269
Mo, H. J., & White, S. D. M. 1996, MNRAS, 282, 347
Moscardini, L., Matarrese, S., Lucchin, F., & Rosati, P. 2000, MNRAS, 316, 283
Nichol, R. C., Collins, C. A., Guzzo, L., & Lumsden, S. L. 1992, MNRAS, 255P, 21
Peacock, J. A., & West, M. J. 1992, MNRAS, 259, 494
Pier, J. R., et al. 2003, AJ, 125, 1559
Postman, M., Huchra, J., & Geller, M. 1992, ApJ, 384, 404
Sheth, R. K., Mo, H. J., & Tormen, G. 2001, MNRAS, 323, 1
Smith, J. A., et al. 2002, AJ, 123, 2121
Spergel, D. N., et al. 2003, ApJS, 148, 175
Stoughton, C., et al. 2002, AJ, 123, 485
Strauss, M., et al. 2002, AJ, 124, 1810
Szalay, A. S., & Schramm, D. N. 1985, Nature, 314, 718
York, D. G., et al. 2000, AJ, 120, 1579
Zandivarez, A., Merchant, M. E., & Padilla, N. D. 2003, MNRAS, 344, 247