The Angular Correlation Function of Quasars from SDSS DR3

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Abstract. We estimate the two-point angular correlation function (CF) of quasars from SDSS DR3 using a special method of comparison random catalog generation. The best-fit value for the CF power-law index is found to be $\alpha = 0.78 \pm 0.18$ on the $2 < \theta < 250$ arcmin interval. This is lower (though in marginal agreement) than earlier result of Myers et al. (2005) based on SDSS DR1 catalogue of photometrically-classified quasars.

Introduction

Two-point correlation functions (CF) of extragalactic objects give us effective means for investigating the large scale structure (LSS) of the Universe. Most complete information can be obtained from the real-space three-dimensional CF, which is convenient for verification of the LSS models. Estimation of this CF is based on linear distances and involves additional (cosmological) parameters. On the other hand, the angular CF is most directly connected with observational data and its estimation practically does not require additional information about the cosmological model. The source of data for CF estimation are extragalactic surveys. When studying the distribution of matter at high redshifts, investigation of quasars is of particular interest, because they are very luminous. In the present paper, we consider the angular two-point correlation function of these objects. We employ the third edition of the SDSS Quasar Catalog (Schneider et al. 2005), which consists of the 46,420 objects brighter than those with absolute magnitudes $M_i = -22$. The area covered by the catalog is $\approx 4188$ deg$^2$. The quasar redshifts range from 0.08 to 5.41, however in this paper we restrict ourselves to $z < 2.4$. Note that the two-point correlation function of objects from the first edition of the SDSS catalogue of photometrically-classified quasars has been estimated by Myers et al. (2005). Here we use the SDSS third data release, which is the result of a more reliable classification method (see Schneider et al. (2005) and references therein).

The surveys of quasars have large redshift depth, but they include fewer objects than the galaxy surveys. This complicates the CF estimation. Furthermore the surveys have their own selection effects, in particular, because of their finite volume, heterogeneity or receiver properties, etc. The essential stage of the CF estimation is the construction of a random catalog taking into account these selection effects as much as possible, which allows to determine the excess of object pairs over random background. There are different methods for such constructions that allow to take into account the initial catalogue properties, and it is useful to verify the results by different statistical means. In the present paper, we use the methodology of artificial catalog generation by Zhdanov & Surdej (2001), which retains some selection effects of the initial catalogue due to the heterogeneity of the spatial sample.

Angular Correlation Function

According to Peebles (1980), the angular two-point correlation function of the object distribution $\omega(\theta)$ determines the probability to find two objects with positions inside small areas $d\Omega_1$ and $d\Omega_2$ on the unit sphere

$$dP = n_0^2[1 + \omega(\theta)]d\Omega_1 d\Omega_2,$$

where $n_0$ is the average object density on the celestial sphere in the area involved. The total number of pairs having separation $\theta \in d\Omega$ is $dN_p = \frac{1}{2}N_t n_0 d\Omega [1 + \omega(\theta)]$, $N_t$ being the total
number of objects in the sample. If there are no pair correlations in a (random) catalogue, the number of pairs equals to \( dN_p^* = \frac{1}{2}N_t n_0 d\Omega \). The excess of the pair number \( dN_p \) over the random background \( dN_p^* \) is
\[
dN_p - dN_p^* = \frac{1}{2}N_t n_0 \omega(\theta) d\Omega. \tag{2}
\]
Estimation of the random background is very important, because it is specific in different catalogues.

It is convenient to use the average number density of pairs from the given range of \( \theta' \) and \( \Delta z \), calculated from the initial catalogue:
\[
n(\theta, \xi) = \frac{N(\theta \leq \theta' \leq \theta + \beta, \xi - \zeta \leq \Delta z \leq \xi + \zeta)}{2\pi \beta (\theta + \frac{\beta}{2})}, \tag{3}
\]
where \( \xi \) and \( \beta \) define the discretization interval for the redshift \( z \) and angle \( \theta \). Also we introduce the similar value \( n^*(\theta, \xi) \) for the randomized catalogue.

Let \( \xi_c \) be a redshift correlation length. Calculation of the excess number \( N_p - N_p^* \) in fact involves only the pairs with \( |\Delta z| < \xi_c \), when we expect a physical relationship between the objects. Therefore, in order to estimate the two-point angular CF according to (2), we use the following relation:
\[
\omega(\theta) = \frac{2[n(\theta, 0) - n^*(\theta, 0)]}{n_0 N_t}, \tag{4}
\]
where we set \( \zeta = 0.1 \), i.e. we include only quasar pairs with \( \Delta z < 0.1 \). Typically we used discretization bin size \( \Delta \theta = 60'' \) and \( \Delta \theta = 100'' \).

Random catalogues were generated using the method of Zhdanov & Surdej (2001). The values of redshift were randomly rearranged in the initial catalogue list of objects, while the values of the right ascension and declination were left in the same order. Hence the real physical correlations of pairs were washed out, but the angular distribution of the quasars has been preserved. In this way we generated 100 randomized catalogues and the value of \( n^*(\theta, 0) \) was obtained as the mean value.

To verify the results we also calculated the pair number densities \( n(\theta, \xi) \) for several values of \( \xi > 0.3 \) and the mean value \( n(\theta, \xi)_{\xi} \) over \( \xi \). For these pairs, no physical correlations are expected. We note the satisfactory coincidence of \( n^*(\theta, 0) \) and \( n(\theta, \xi)_{\xi} \) within the wide range of angle values; this testifies the good quality of the randomized catalogues.

Results

The values of the two-point angular correlation function (Fig. 1), defined by formula (4), were approximated by the dependence
\[
\omega(\theta) = a + b\theta^{-\alpha}, \tag{5}
\]
where \( \alpha \) is the index of the correlation function; the constant \( a \) has been introduced to compensate possible uncertainty of the background pair numbers, but it was found to be statistically insignificant. The results were checked for different regions of SDSS DR3. The best-fit values of \( \alpha \) are presented in Table 1 for the quasars with \( 0.3 < z < 2.4 \). For comparison the results from Fig. 5 of Myers et al. (2005) are also presented.
Figure 1. Two-point angular correlation function $\omega(\theta)$ and its approximation (5).

Table 1. Index of the two-point angular correlation function

| Source        | $\alpha$     | Interval, arcmin |
|---------------|--------------|-----------------|
| SDSS DR3      | 0.70 ± 0.14  | [1,250]         |
| SDSS DR3      | 0.84 ± 0.22  | [5,250]         |
| SDSS DR3      | 1.05 ± 0.20  | [3,150]         |
| SDSS DR3      | 0.93 ± 0.27  | [5,150]         |
| SDSS DR3      | 0.78 ± 0.18  | [2,250]         |
| SDSS DR1 Myers et al. (2005) | 0.98 ± 0.15  | [2,250]         |

Discussion

The result of fitting on the largest interval $1 < \theta < 250$ arcmin is $\alpha = 0.70 \pm 0.14$. As one can see from Table 1, our results are in marginal agreement with that of Fig.5 from Myers et al. (2005) within $2\sigma$ errors. On the other hand the parameter $\alpha$ in the case of quasars is not found to be essentially larger than the usual value $\alpha \approx 0.7$ for galaxies, including more detailed galaxy type analysis (e.g., Connolly et al. 2002, Budavary et al. 2003). Different values of $\alpha$ on different scales may be due to poor statistics; however we cannot cast aside a possibility that this is a result of LSS peculiarities like cellular structures. Anyway the function (5) may be considered only as an approximate model (cf., e.g., Connolly et al. 2002, Myers et al. 2005). We tried to modify (5) for small angles, but this did not give rise to any statistically significant results.

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References

Budavary, T., Connolly, A.J., Szalay, A.S. et al., Angular Clustering with Photometric Redshifts in the Sloan Digital Sky Survey: Bimodality in the Clustering Properties of Galaxies, ApJ, 595, 1, 59-70,
Connolly, A.J., Scranton, R., Johnston, D., et al., The Angular Correlation Function of Galaxies from Early Sloan Digital Sky Survey Data, ApJ, 579, 1, 42-47, 2002.

Myers, A.D., Brunner, R.J., Richards, G.T., et al., First Measurement of the Clustering Evolution of Photometrically Classified Quasars, ApJ, 638, 2, 622-634, 2006.

Peebles, P.J.E. "The Large Scale Structure of the Universe. Princeton Univ. Press", 1980.

Schneider, D.P., Hall, P.B., Richards, G.T. et al., The Sloan Digital Sky Survey Quasar Catalog. III. Third Data Release, AJ., 130, 367, 2005.

Zhdanov, V.I., Surdej, J., Quasar pairs with arcminute angular separations, A&A, 372, 1-7, 2001.