Clustering and Velocities of Quasars from SDSS

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Abstract: We present a method of determination of the cosmological parameters using the local isotropy of quasar clustering. Using the Fifth Data Release of the SDSS we obtained the following estimation of the quasars peculiar velocity dispersion v_{pec} =762±221 km/s for the slope of the real-space correlation function γ=1.9.

1. Introduction

The isotropy of Universe implies that the distribution of extragalactic objects must be locally isotropic in the average. Following Alcock and Paczynski [1], the idea of local isotropy has been repeatedly used to determine cosmological parameters. This involves, in particular, investigation of the two-point correlation functions and power spectrum of the distribution of galaxies, quasars and galaxy clusters (see, e.g., [6,7,10,13]). But correlation functions and power spectrum of extragalactic objects are distorted due to their peculiar velocities, which give additional contribution to the redshifts leading to wrong values of coordinates along the line-of-sight.

Different inputs are due to random peculiar velocities, velocities of gravitational infall of the matter into overdense regions and velocity dispersion in virialized clusters of galaxies ("Fingers of God", β-distortion [9], or Kaiser effect); these result in deformation of the correlation function along the line of sight in the redshift space. Note that the quasars have not been virialized yet, the most part of them represent earlier times at which clusters were only forming, but the β-distortion must be significant. Having the geometry of the Universe dictated by spatially flat ΛCDM we may use the observed redshift-space distortions to estimate the velocities of quasars with respect to the cosmological background. In the present work we present the results of our estimation of the quasars peculiar velocity dispersion.

2. The Data

For our studies we used a sample of 46315 objects from the Fifth Release of the Sloan Digital Sky Survey (SDSS DR5) [2] which were primarily identified as quasars and have redshifts within the range [0.8,2.2]. This data is available on http://www.sdss.org/dr5/products/spectra/getspectra.html. Given redshift range was chosen first of all as the most populated by quasars, and secondly due to the best efficiency of the photometrical classification technique.

For verification of the reliability of the redshifts indicated in this data we compared this sample with the SDSS Quasar Catalogue IV (QC IV), constructed on the base of the SDSS DR5. The detailed description of this catalogue can be found in [15]. We note only that due to specific technique of its construction it does not present a statistical sample. Thus it cannot be used in our studies. Moreover, it also has a lack of close pairs interesting for us, as its previous edition [8,16]. We compared the objects from our sample and QC IV and found 45911 objects, for 72% of which coordinates α, δ coincide accurate within 0°.000001 and for others they coincide within astrometry errors of SDSS (0".001). The results of such comparison reveal the coincidence of the redshifts in SDSS DR5 with those from QC IV within 0.5%.

3. The pairwise velocities estimation

Let $f_1(\mathbf{r}) \equiv f_1(r,\theta)$ be the distribution function of the neighbours of a quasar within the catalogue volume V_{cat}, where $\mathbf{r}$ is a radius-vector of the neighbour in the comoving reference frame. Hereafter all the distances are measured in the local reference frame on an observer related to the quasar. We assume this neighbours distribution to be the same for all quasars, i.e. we neglect correlation of higher orders. The probability to find the quasar in the volume *dV* is $dP = f_1(r)dV$. The probability to find any quasar from the sample in the volume *dV* is

$$dP_N = f_N(\mathbf{r})dV = n_0[1+\xi(\mathbf{r})]dV\,,\quad f_N(\mathbf{r}) \approx Nf_1(\mathbf{r})\,, \tag{1}$$

where $\xi(\mathbf{r})$ is the two-point correlation function according to Peebles' definition [12], $n_0 = N_{cat}/V_{cat}$ is the mean objects density. Note that in our further calculations we use the value $n_0(z)$ which is a function of the redshift.

The space in which objects' coordinates along the light of sight are calculated without taking peculiar velocities of the objects into consideration is called the "redshift space". The distance perpendicular to the line of sight in this space is the same as in the real space, but the distance along the line of sight is equal to $\Delta\pi = \Delta\pi_{phys} - v/H_0$, where $\Delta\pi_{phys}$ is a real space distance, *v* is a pairwise velocity of the objects. Taking into consideration the objects peculiar velocities the mean quasar distribution (1) in the redshift space differs from the spherically symmetrical one due to 'Fingers of God' effect and β-distortion. In the case of β-distortion quasar velocities are not independent and correlate with the matter density fluctuations. Such deviation of $f(\mathbf{r})$ and $\xi(\mathbf{r})$ from spherical ones are important and actually are the only one source of information about quasar peculiar velocities. But calculations of them are usually based on some approximations and model assumptions. Thus we fix on the model-independent characteristics of $\xi(\mathbf{r})$ in the redshift space.

We introduce the following value

$$q_m(r) = 2\pi\int_{-1}^{1} f_1(\sigma,\pi)P_m(\mu)d\mu = \frac{2\pi}{V_{cat}}\int_{-1}^{1}\xi(\sigma,\pi)P_m(\mu)d\mu\,, \tag{2}$$

where $\pi = r\mu$, $\sigma = \sqrt{1-\mu^2}$, $\mu = \cos(\theta)$, $P_m(\mu)$ are Legandre polynomials. It is convenient to use integral values

$$Q_m(r,\Delta r) = \frac{\int_{V(r,\Delta r)} f_1(\sigma,\pi)P_m(\mu)d^3\mathbf{r}}{V(r,\Delta r)} = \frac{\int_r^{r+\Delta r} q_m(r)r^2dr}{V_{cat}V(r,\Delta r)}\,, \tag{3}$$

which are the mean values of q_m in the spherical layer between *r* and *r*+Δ*r* which has a volume $V(r,\Delta r) = 4\pi\Delta r[r^2 + r\Delta r + (\Delta r)^2/3]$.

For estimation of the values Q_m we use the following values which could be calculated from the observational data

$$Q_{E,m}(r,\Delta r) = \frac{1}{n_0 V(r,\Delta r)}\sum_i\sum_j P_m(\mu_{ij})w_{ij}\,, \tag{4}$$

where w_{ij} is equal to 1 if $r_{ij} \in [r, r+\Delta r]$ and 0 if $r_{ij} \notin [r, r+\Delta r]$. The sum of the values $P_m(\mu_{ij})$ over j is calculated over all neighbours of the quasar with a separation $r_{ij} \in [r, r+\Delta r]$ from it, and then it is averaged over all *i*=1,2,…,*N* quasars from the sample.

For a fixed *i* one estimate the mean value of (4) taking into consideration the probability distribution (1) and find that it is equal to those defined by (3), i.e. the value (4) calculated with the help of experimental data gives us an unbiased estimate of the moments (3).

Using our sample of quasars we calculated the values of $Q_{E,m}(r,\Delta r)$ for *r* within the range from 2 to 40 Mpc for m=0,2 with Δ*r*=2 and obtained the following relation $Q_{E,2}(r,\Delta r)/\,Q_{E,0}(r,\Delta r)$.

On the other hand we modeled the theoretical relation $Q_2(r,\Delta r)/\,Q_0(r,\Delta r)$ using the power-low form of the correlation function

$$\xi(r) = \left(\frac{r_0}{r}\right)^{\gamma}\,, \tag{5}$$

where γ is a slope of the correlation function. We used for the estimates two values of γ: 1.7 and 1.9. The last one is more appropriate for quasars [11]. We used the following approximation of the correlation function in the redshift space [6]

$$\xi(\sigma,\pi)=\xi_0(s)P_0(\mu)+\xi_2(s)P_2(\mu)+\xi_4(s)P_4(\mu)\,, \tag{6}$$

where for the power-low correlation function

$$\xi_0(s)=\left(1+\frac{2\beta}{3}+\frac{\beta^2}{5}\right)\xi(r)\,,\quad \xi_2(s)=\left(\frac{4\beta}{3}+\frac{4\beta^2}{7}\right)\xi(r)\,,\quad \xi_4(s)=\frac{8\beta^2}{35}\frac{\gamma(2+\gamma)}{(3-\gamma)(5-\gamma)}\xi(r)\,,$$

Here $\beta\approx\Omega^{0.6}/b$, b is the bias parameter. We also used the following convolution of $\xi(\sigma,\pi)$ with the distribution function of random pairwise velocities $f(v)$

$$\xi(\sigma,\pi)=\int_{-\infty}^{+\infty}\xi(\sigma,\pi-v/H_0)f(v)dv\,, \tag{7}$$

where $f(v)$ has an exponential form [14]

$$f(v)=\frac{1}{a\sqrt{2}}\exp\left(-\frac{\sqrt{2}\,|v|}{a}\right). \tag{8}$$

4. Results

All calculations of the experimental values $Q_{E,2}(r,\Delta r)/\,Q_{E,0}(r,\Delta r)$ were done within the flat ΛCDM-cosmological model with spatially flat Universe and Ω_M=0.29, h=0.73. The resulting estimations of the velocities of quasars v_{pec} with respect to the cosmological background for different values of parameter β are presented in the Table 1. Corresponding values of b were calculated assuming that Ω_M=0.29.

Table 1. Quasars peculiar velocity dispersion.

β	b	v_{pec}, km/s (γ=1.9)	v_{pec}, km/s (γ=1.7)
0.15	3.17	549±180	515±223
0.20	2.39	762±221	651±263
0.25	1.90	1017±255	854±307
0.30	1.59	955±322	945±335
0.35	1.36	878±375	901±366
0.40	1.19	798±417	856±389

As it is known from the other estimations (see [3] and references therein), the value of the bias parameter for quasars is about 2 for the mean z=1.5. Generally speaking the bias parameter is a function of the redshift [4]. Authors of the paper [11] obtain the values b=3.93±0.71 integrating across all redshifts and b=2.41±0.08 for $\bar{z}=1.4$ for photometrically classified quasars from SDSS. For quasars from 2dF QSO Redshift Survey the authors of [4] found b=2.02±0.07 for $\bar{z}=1.35$. Taking into account that the mean redshift of our sample is 1.5 , the most reliable estimation of the peculiar velocity is v_{pec} =762±221 km/s for γ=1.9.

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