# SEARCHING OF FLAT WAVES OF DENSITY IN SPATIAL DISTRIBUTION OF QUASARS

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Periodicity in galaxy distribution on distances was detected in pencil beams of deep redshifts surveys of galaxies. A priori probability of the appearance of such periodicity is $10^{-8}$ [5] even at the presence of the selected scale in a correlation function. Eynasto *et al.* [4] exposed a moderately regular net structure in the distribution of rich clusters of galaxies and voids. They consider that it must be due to a process unknown before. It can be assume that in some directions there are flat waves of density. The discovery of periodicities in pencil surveys is possible not far from these directions. Superposition of waves of different directions and with different periods can lead to the appearance of regular net structure. The search of flat waves of density in the spatial distribution of quasars with the periods in the range (230–700) $h^{-1}$ Mpc, most favourable for their exposure, has been carried out. The samples of quasars from catalogues of Veron-Cetti, Veron and 2QZ 10k were used. While scanning the sky the power spectra of quasars distribution along an axis of sight were analysed. Four flat waves, presented in various not intersected samples with periods coincided within the limits of spectral resolution and with close phases were detected. Estimations of parameter of density have been made in each of them. Mean value is $0.29 \pm 0.02$ (95% confidence limit).

## INTRODUCTION

Broadhurst *et al.* [1] in their sharply-directed (pencil) deep surveys of the sky in northern and southern hemispheres oriented along the axis of a galaxy rotation have found out the period $130\,h^{-1}$ Mpc in the galaxies distribution with a general extension $1800\,h^{-1}$ Mpc. In two short, unilateral surveys in almost perpendicular directions (toward Hercules and toward Perseus) the periods 110 and $140\,h^{-1}$ Mpc have been detected. In spatial power spectra of several sets of galaxies, clusters and superclusters a peak corresponding to a characteristic length of large-scale structure of the Universe $L_S \simeq 130\,h^{-1}$ Mpc (see [2]; the survey [5]) emerged many times. At large redshifts the similar scale was detected in the spacing of quasars in the range of $1.8 < z < 2.4$ [7]. Einasto *et al.* [4] have revealed three-dimensional moderately regular net structure with a step $\simeq 120\,h^{-1}$ Mpc from rich clusters and voids. They claim that there should be a process obscure till now producing regular spatial net of large scales.

Apparently, the appearance of periodicity detected in [1], is impossible to explain by the existence of an internal scale in a spacing of quasars. The relevant results here were obtained while simulating the appearance of periodicities in the sharply-directed surveys of galaxies, when there is a selected scale $L_S$ in correlation functions of their distributions. The prior probability of the appearance of periodicity turned out to be much below $10^{-3}$ [10] and about $10^{-8}$ [5]. The periodicity in the various-directed pencil surveys is detected at different frequencies. It does not agree with the idea of general periodicity existing in radial coordinate. On the other hand, probability of appearance of radial periodicity in the pencil surveys even at the presence of a reference scale in a spacing of galaxies is very small. These difficulties can be eliminated if to admit, that in space not spherical, but flat waves of density exist along the axes $X(\alpha, \delta)$. Then, if the direction of the pencil survey is close to a direction of the $X$ axis, the corresponding period can be detected in the distribution of objects on radial coordinate. Such periodicities with close periods in various directions will cause the appearance of a reference scale and net structure in a spacing of objects. The search for density flat waves in a spacing of quasars has been carried out.

## BASIC FORMULAS

At a given direction of the $X$ axis of an arbitrary point coordinates are equal to $x = r\cos\theta$ and $q = r\sin\theta$, where $r$ is a radial coordinate, $\theta$ is an angle between a beam passing through a point and the $X$ axis, $q$ is the distance of a point from an axis. In a flat universe density parameter $\Omega_m$ and dimensionless cosmological constant $\Omega_\Lambda$ are related by ratio $\Omega_\Lambda = 1 - \Omega_m$. Scalable proper distances can be stated by the relation

$$r(\Omega_m, z) = d(\Omega_m, z)[\ln(1+z_1)/d(\Omega_m, z_1)].$$

Let us accept $\ln(1+z_1) = 1.5$, as for the majority of quasars $z < z_1 = 3.482$. With such scaling peak frequency in SPS quasar distribution on argument $r$ at changing density the parameter vary unsignificantly, and its value is close to peak frequencies in SPS for quasar distribution on argument $\ln(1+z)$.

The sample power spectra (SPS) $S_\omega$ for quasar distribution on coordinate $x$ and initial phase $\varphi$ at frequency $\omega$ were calculated by standard formulas. To decrease a minor-lobe level the SPS were calculated by means of Hann window.

The estimation of the sample power spectra was performed on the statistics of SPS of its segments. The sample was divided into $s$ segments with equal number of objects. At frequencies of interest, the averaged periodogram $P_\omega$ and error of mean $\sigma_P$ were calculated. As the criterion of a signal presence at frequency $\omega$ the value

$$p_\omega = \frac{P_\omega - 1}{\sigma_P}$$

was used. Since SPS are normalized on a single dispersion, mathematical expectation $(P_\omega - 1)$ is equal to zero.

## DATA

The samples with enough even distribution of quasars on the sky are necessary for successful searching of flat waves of density. As the source for the producing samples Veron-Cetty and Veron [9] catalogue quasars was used. The sample approximately uniformly distributed on the sky of radioquiet quasars (QGI) was built. The objects number in samples radioquiet (QGI), radioloud quasars (QR) and in integrating them (QRG) is equal to 1924, 2830, and 4754, respectively.

The catalogue of quasars 2QZ 10k [3] with values $18.25 < B_j < 20.85$ was also used. In sample 2QZ the quasars with reliable $z$ and identification were selected. The sample size was 10689 quasars with $z$ from 0.1 up to 3.2.

## METHOD AND RESULTS

Periodicity in the distribution of quasars on the $X$ axis will be called a flat wave. The flat wave $X_\omega(\alpha, \delta)$ is determined by the direction of the $X$ axis and its period $P$ or angular frequency $\omega$. If $X_\omega(\alpha, \delta)$ exists, it should be present in various of quasars samples representative enough.

While searching the flat waves not intersected samples QR and QGI covering the whole sky were used. The periods 0.1 ($25 < \omega < 50$) are optimal for the searching. We can allocate three stages in our searching procedure.

1. The initial searching periodicities were carried out in the sample QR in the small cylinder C ($|x| < 0.5$, $q < 0.5$). Internal ($q < 0.25$) and external ($q > 0.25$) parts of the cylinder will be designated as C1 and C2, respectively. Into these volumes the quasars forming two not intersected samples have fallen. At scanning of the whole sky the directions $X(\alpha, \delta)$ were located, where there are peaks with $S_\omega > 3$ in the SPS of those samples conterminous with a frequency in the resolution limits and in a sample C there is a peak ($S_\omega > 5$) at the same frequency. Further, SPS of the whole sample QR ($|x| < 1.5$, $q < 1.5$) in neighborhood of a selected direction was calculated. If the peak on the selected frequency was present at the SPS, the method of its maximization was used to updated the direction of an axis and when $S_\omega(C) > 4$ and $S_\omega(QR) > 6$ they were actuated in the candidate list $X_\omega(\alpha, \delta)$. 13 candidates in total were detected.

2. For selected directions SPS of the whole sample QGI were calculated. In five directions SPS there are peaks at frequencies close to those of retrieved in the sample QR ($|\Delta\omega| < 3$) with $S_\omega > 2$ and with the difference of phases $|\Delta\varphi| < 60°$. In accordance with the hypothesis of white noise a probability to meet peak with $S_\omega > 2$ at earlier known frequency and the difference of phases $|\Delta\varphi| < 60°$ equals to 0.05. Having computed the probability of appearance of the such five events through 13 tests, we shall find that the hypothesis of white noise is disclaimed on the level of significance $5 \cdot 10^{-4}$.

3. The parameters $X(\alpha, \delta)$ were updated along the whole sample QRG. For four candidates the angle between directions in sample QR and QRG does not exceed 1.5°. In the direction of 26–20 this angle is equal to 3.0° that considerably exceeds an error of its determination. The parameters of four left periodicities are listed in Table 1. In Fig. 1 the SPS of QRG, QR, and QGI samples are routined for each of these directions.

Table 1. The parameters of periodicities in the sample QRG for selected directions $(\alpha, \delta)$: $\omega$ , $\varphi$ are the frequency and phase, respectively, $S_\omega$ is the peak height, $p_\omega$ is the criterion of the availability of periodicity while dividing the sample into 5 and 10 segments, $P$ is the period, $\Omega_m$ is the estimation of the density parameter

| $n$ | $\alpha$ | $\delta$ | $S_\omega$ | $\omega$ | $\varphi$ | $p_\omega(5)$ | $p_\omega(10)$ | $P$ | $\Omega_m$ |
|---|---|---|---|---|---|---|---|---|---|
| | deg | deg | | | deg | | | $h^{-1}$ Mpc | |
| 1 | 4.1 | −30.0 | 12.2 | 55.5 | 295 | 3.2 | 2.3 | 360 | 0.29 |
| 2 | 36.3 | −37.9 | 9.5 | 37.7 | 247 | 2.6 | 1.8 | 530 | 0.31 |
| 3 | 111.2 | 27.9 | 11.2 | 65.1 | 6 | 2.6 | 3.9 | 310 | 0.30 |
| 4 | 124.5 | −50.9 | 9.2 | 52.1 | 151 | 3.0 | 3.3 | 380 | 0.26 |

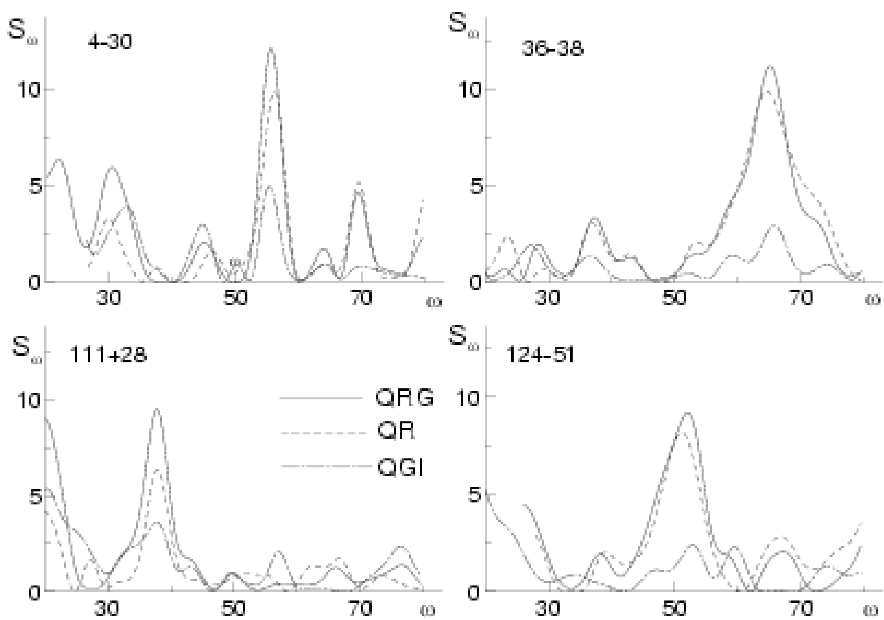


Figure 1. SPS for not intersected samples QR and QGI and integrated sample QRG. Numbers in figures are the coordinates of the $X$ axis direction in grades

For the checking test it is possible to use sample 2QZ. Only in the direction 111+28 the distributions of quasars are favourable for SPS calculation. Here in SPS there is a peak at frequency close to an expected ($\Delta\omega = 0.4$, $\Delta\varphi = 65°$) that is proved independent.

While spectral estimation the sample QRG was divided into $s$ segments. For this purpose, the quasars were ordered by coordinate $q$ – distance from the $X$ axis. Each segment included equal quantity of objects ($N/s$) between corresponding cylindrical surfaces. In Table 1 the results of estimation are shown while dividing the sample into 5 and 10 segments. Maximum of $p_\omega$ is observed near to the peak frequencies of SPS. In peaks $P_\omega$ exceeds a hum level by (2–4) $\sigma_P$. The estimation carried out confirms the presence of periodicities at selected directions.

In Fig. 2 the relations of a peak height to the parameter for the detected periodicities are routined. In all four cases the maxheights of peaks are reached when $\Omega_m \simeq 0.30$. The corresponding option values density parameter for each wave are shown in Table 1.

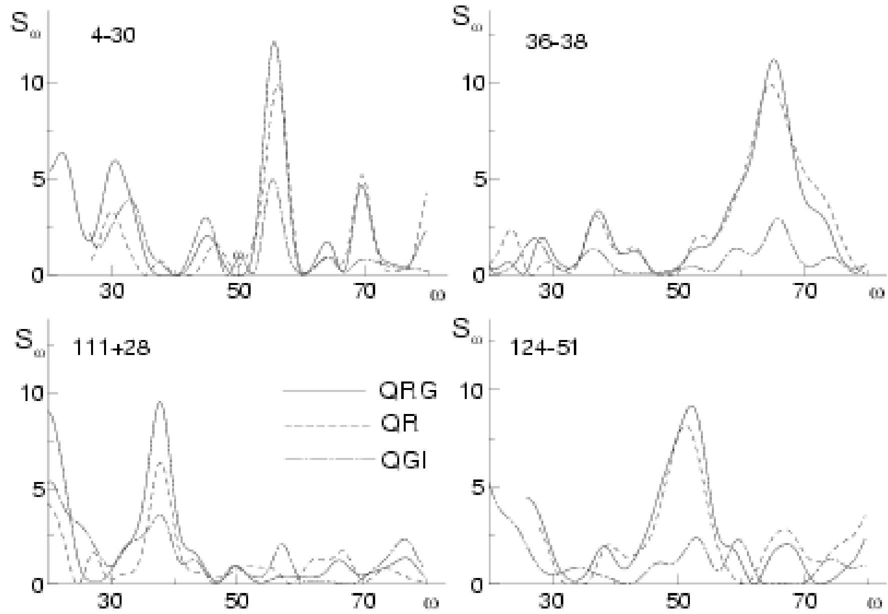


Figure 2. The relation of a peak height $S_\omega$ in SPS of the sample QRG and the parameter of density $\Omega_m$ in four selected directions of the $X$ axis

The average value of parameter equals to $\Omega_m = 0.29 \pm 0.02$. Our estimation of density parameter will agree with the value $\Omega_m = 0.27 \pm 0.04$ obtained by Spergel *et al.* [8] at the analysis of the set of WMAP results and other astronomical data.


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