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IN SEARCH FOR QUASAR REDSHIFT PERIODICITY

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The history of the quasar redshift periodicity studies is presented, including both the first investigation showing the possibility of the existence of this phenomenon and the recent result based on an objectively defined quasar sample. Possible theoretical explanations of quasar redshift discretization are mentioned. Selection effects leading to redshift quantization pointed out in the current literature are discussed.

Представлена история изучения периодичности красного смещения квазаров, начиная с первого исследования, показавшего саму возможность существования этого явления, и заканчивая последними результатами, основанными на объективно существующем примере. Упоминаются возможные теоретические объяснения дискретизации красного смещения квазаров. Обсуждаются также указанные различными авторами эффекты отбора, ведущие к наблюдаемому квантованию красного смещения.

The search for possible periodicity in quasar redshift distribution has been an important question from both observational and statistical points of view. The main interest in this matter concerned possible interpretation of the effect. The existence of such periodicity combined with the lack of a known underlying mechanism, constituted an observational basis for claims invoking new physics at work.

Usually, explanations were made in the framework of a version of steady state cosmology. For example, Jaakkola [1] proposed the so-called Equilibrium

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Cosmology where the Universe neither expands nor changes globally. In such cases the reddening of light is not due to the Doppler effect. The wavelengths of photons increase as the latter travel through space. So, the length units of a metric correlated to the characteristic quantities of photons, change relative to the length units of a metric correlated to the characteristic quantities of elementary particles; the electromagnetic signal carriers are false messengers. So, they should be corrected which is leading to «fib cosmology» [2]. This leads to nonlinearity of redshifts. The variability of the speed of light [3], as well as the Wave Universe Concept [4, 5], were also involved in the explanation of redshift periodicity.

The first peculiarity which striked cosmologists looking for an explanation of quasar redshift distribution was the excess of quasars with $z < 2$ (close to $z = 2$). The nature of quasar redshifts was the main subject of early quasar investigations. There have been three interpretations of quasar redshifts. The redshifts are either strictly Dopplerian, or a part of the redshift is Dopplerian but there is also a non-Dopplerian term, or else strictly non-Dopplerian (i. e., the «tired-light hypothesis»). So the main question was whether redshifts are cosmological (like those of galaxies), which means that they are connected with distances, or not.

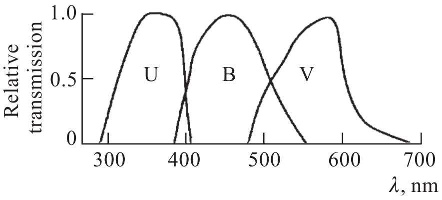

Fig. 1. Bandpasses for a broad-band UBV photometric system

Detection of quasars is not simple because they are dim point-like objects. Usually they are detected through sky survey at several wavelengths. This allows one to discriminate between objects with nonstellar colour. Photometrically selected objects are candidates for quasars. Further spectral observations are decisive to classify them as quasar or non-quasar objects. The basic feature is the UV excess for objects brighter than $M = -24^m$. The QSO spectrum is characterized by several prominent emission lines. These are, among others: Ly α ($\lambda_{\rm rest} = 1216$ Å), Si IV ($\lambda_{\rm rest} = 1400$ Å), C IV ($\lambda_{\rm rest} = 1549$ Å), C III ($\lambda_{\rm rest} = 1909$ Å), Mg II ($\lambda_{\rm rest} = 2798$ Å), $\rm H_\delta$ ($\lambda_{\rm rest} = 4101$ Å), $\rm H_\gamma$ ($\lambda_{\rm rest} = 4340$ Å), $\rm H_\beta$ ($\lambda_{\rm rest} = 4861$ Å) and [O III] ($\lambda_{\rm rest} = 4959$ Å and 5007 Å). However, high-redshift quasars cannot be detected by this method. At $z = 2.1$ the strong emission line Ly α is shifted from ultraviolet to blue filter B (of the UBV photometric system, see Fig. 1).

Thus, this approach, so characteristic for quasar UV excess and photometry, is no longer a good method to search for quasar candidates, because the sample becomes incomplete. The other method of quasar detection is low-dispersion spectrometry using an objective prism. This method is not as sensitive as the previous one, but can be applied to objects with greater redshift. The main difficulty in quasar detection is the problem of sample completeness. X rays and radio surveys are also involved when finding quasar candidates. But only optical observations make it possible to discover strong emission lines characteristic of quasars. The redshifts of quasars and quasar-like objects are determined from measurements of both absorption and emission lines in their spectra. Moreover, it should be stressed that due to the lack of knowledge of quasar nature and the sources of quasar energy, the overwhelming majority of authors tried to find a correlation between the values of observational parameters. This is very characteristic of each branch of science at the early stages of its development.

Burbidge's [6] investigations of quasar absorption and emission line concordance gave rise to this problem. In 1968, he noted redshift grouping around the values of $z = 0.01$ and $z = 1.95$. He also found periodicity in redshift distribution, which can be described by the formula $z_{\mathrm{obs}} = 0,061n$. This periodicity is well observed for some values.

In 1969, while analyzing their catalogue data, the Burbidges [7] discovered the existence of sharp peaks in redshift distribution. Their sample extended as far as $z = 1.95$, and multiplication of $z = 0.06$ was suggested.

Having analyzed four strong emission lines Mg II, C III, C IV and Ly α in the quasar spectrum, Karitskaya and Komberg [8] were the first ones to note their shift towards the B filter of the UBV photometric system. In this manner they explained qualitatively the existence of minima and maxima in the quasar redshift distribution.

The Burbidge result was criticized by Roeder [9]. He showed that redshift measurements for objects from Burbidge's list are dubious due to the problematical identification of lines in the quasar spectra, as well as the inaccuracy of doublets and blend measurements. The heterogeneous treatment of spectral lines gives five bins with widths of $\Delta z = 0.1$, in which only 6 objects are observed. It is obvious that in these bins the mean values cannot be calculated, which makes the application of some statistical tests impossible. The analyzed distribution is clearly nonrandom, so the search for periodicity based on statistics with assumed random distribution is incorrect. The difficulties of a correct application of statistics pointed out by Roeder were repeated later by several authors. Some lines are measured more easily than others, which led to the lack of quasars within particular redshift intervals. This observational effect causes an artificial selection which, together with incorrectly applied statistics, gives spurious periodization of quasar distances to the observer. Roeder noted that the spectral line Mg II (usually used for redshift determination for nearby quasars) is shifted for $z = 1.25$ beyond the observed spectral range, thus causing the local minimum in redshift distribution. At $z = 1.8$, the shifted Ly α line enters the blue region of the visual spectrum. These two effects considered together yield the minima and maxima observed in the redshift distribution. Essentially the same conclusion was reached by Semeniuk and Kruszewski [10], who independently analyzed the sample of 178 QSO with emission lines. Later on, this was confirmed by Basu [11].

Cowan [12] found a strong peak with a period $0.1666z$ (or $z/6$) based on 116 objects. One year later the sample containing 178 objects was a basis for his conclusions [13] that the periodicity is $z/6$ and $z/16$. In both papers spectral analysis was applied. The same sample was analyzed by Deeming [14]. He found a lack of statistically significant departure from the expected, random distribution. He wrote: «Of course, like any statistical test of significance, this is one-way; it allows us to accept the hypothesis that the original data were random, but does not necessarily reject the hypothesis that the data were nonrandom. If the original data were random, then probably seven or so more points could be discovered in the power spectrum at still higher power levels».

Karlsson [15] noted the existence of five broad peaks in the distribution under discussion. Their statistical significance was checked using the autocorrelation test. In the $\log(1+z)$ variable their period is 0.089, which gives the observed maxima at $z = 0.3$, 0.6, 0.96, 1.41, 1.96, and two other ones predicted at $z = 2.63$ and 3.46. Similarly, Barnothy and Barnothy [16] found the period of 0.085 in the $\log(1+z)$ variable.

The observed redshift distribution similar to that given in Fig. 2 was compared by Roeder and Dyer [17] with two theoretical ones, namely the uniform distribution and the smoothly decreasing one for $z > 0.4$. They concluded that both theoretical distributions are different from the observed one at the significance level $\alpha = 0.01$, which confirms the statistical significance of maxima and minima in redshift distribution. The correlation between the wavelengths of the lines in quasar spectra and the spectral lines of the night sky is observed. So, the possible overlapping of these lines makes redshift an ill-defined observable.

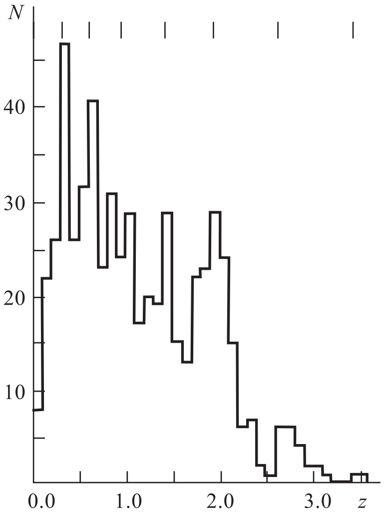

Fig. 2. Distribution of QSO redshifts based on Karlsson sample. Bars indicate positions of peaks (reproduced with kind permission of Dr Per Kjaergaard)

Plagemann et al. [18] improved the application of the PSA method for investigating the redshift distribution. This method is practically the only one in use now. Their study, based on 186 objects, does not detect any periodicity. One should remember here that for scientists of the time the most interesting hypotheses were those of cosmological and local origin of quasar redshifts. So, the main goal of their work was to perform an analysis from the point of view of possible existence of two quasar redshift populations. Using 1-dimensional PSA, quasar redshift distribution was reanalyzed by Lake and Roeder [19]. They found periodicity in $z = 0.007$, as well as a possible period of 0.0264. This finding concerned both quasars and strong-emission-line objects. When restricting analysis to quasars, only a few distinct maxima were observed. Each particular maximum was not significant statistically, but a comparison with numerical simulations clearly 'showed a non-random redshift distribution. The probability of the existence of three such clear peaks in random distribution was only $6{\cdot}10^{-4}$. A similar analysis but for a greater number of objects was performed by Burbidge and O'Dell [20]. They considered three samples. The first sample contained quasars with redshifts determined with emission lines only. In the second one redshifts came from absorption lines, while in the third sample they originated from both types of lines. Burbidge and O'Dell found the peak around $z = 0.03$, but the peaks previously noted at $z = 0.06$ and $z = 1.95$ were absent. The peak at $z = 0.03$ is probably responsible for the claimed period of $z = 0.031$. They pointed out that periodicity depends on data binning. The analysis performed with bin widths of $\Delta z = 0.01$ showed random distributions. Thus, Burbidge and O'Dell concluded, «Of course, one such example proves nothing; however, it does demonstrate the difficulty in determining the reality or nonreality of small-scale features when small numbers are involved».

It was shown by Karlsson [21] that the observed distribution of quasars cannot be explained by the selection effects pointed out by Roeder; Roeder and Dyer; and Basu. In Karlsson's opinion, they incorrectly assumed the uniformity of redshift distribution. In his next work [22], Karlsson enlarged the analyzed sample to 574 objects. By applying power spectrum analysis (PSA), he revealed periodicity which can be described by a geometrical sequence with a quotient equal to 1.227. Bell and Fort [23] assumed that quasar redshift consist of two components: z_c and z_x, where z_c is the cosmological term, while z_x is a redshift of unknown origin in the source. The observed redshift z can be written as

$$1 + z = (1 + z_c)(1 + z_x).$$

Bell and Fort found that the z_x distribution for radioquasars is correlated with their absolute magnitude. The quantized absolute magnitude can be written as

$$M_v = -20.4 + 1.06 z_x.$$

The hypothesis of redshift periodicity has been tested [24] using the sample of 540 strong-emission-line redshifts. PSA did not reveal any periodicity. The majority of the previously reported peaks in redshift distribution disappeared, and the remaining ones were statistically insignificant. The sample of 400 objects, analyzed by Corso and Barnothy [25] by means of PSA, also gave a negative result, revealing no periodicity in quasar redshift distributions.

When discussing the conclusions of previous investigations that periodicity, found at a great significance level, is not a result of selection effects, Kjaergaard [26] pointed out that the appropriate statistical model has to incorporate the selection effect in order to ensure correctly determined statistical significance.

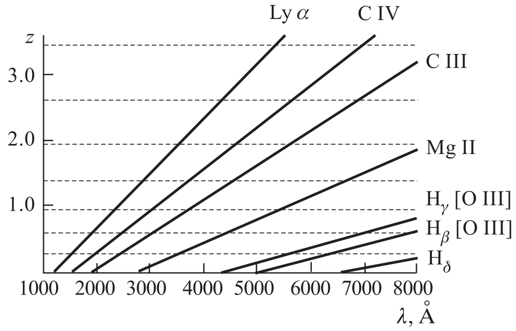

Fig. 3. Relation between redshift and observed wavelengths for strong emission lines. Positions of Karlsson's z values are indicated by broken lines (reproduced with kind permission of Dr Per Kjaergaard)

Moreover, Kjaergaard considered the relation between the redshift and the observed wavelengths of strong emission lines. He found that «there is a distance of 0.0905 ± 0.007 between adjacent values of the logarithm to the rest-wavelengths of the stronger lines». So the majority of the strong emission lines are at rest-wavelengths for $z = 0$ at 1239, 1526, 1880, (2315), 2852, (3512), 4326, (5328), and 6563 Å (see Fig. 3). If periodicity is observed for rest-wavelength, it should be observed in $\log \lambda_{\rm rest}$ and, of course, it will appear in $\log(1+z)$ for a fixed wavelength of the photometric system. Such a factor corresponds to 1.232 between neighbouring rest-wavelengths in $\log(1+z)$ which is very close to the value of 1.227 found by Karlsson. Kjaergaard returned to the quasar selection methods. Considering the diagram U–B vs z for typical quasars, he was able to show that it is quite similar to the redshift histogram for quasars detected using UV excess. Moreover, he was able to show that methods of quasar selection, such as coincidence between radio and optical positions, as well as spectroscopic selection, exhibit several maxima which can be responsible for the claimed redshift periodization.

Further analysis [27] performed using the PSA method and based on 1491 quasars and 58 BL Lac objects distributed in the redshift range $[1.17, 5]$ confirmed Karlsson's result. The analysis of this sample by Box and Roeder [28] allowed them to detect the period of 0.85 in z at the significance level of 97 %. However, the result could be due to the selection effect which follows from the comparison of various subsamples. The periodicity of 0.205 in $\log(1+z)$ is due to the sample cutoff for high z and to its incompleteness. The additional analysis of subsamples displayed a low level of significance, i. e., only 81 %.

Depaquit et al. [29] pointed out that periodicity in the quasar redshift distribution could be the result of one of the effects described below or of their combination. These effects are:

1) presence of selection effects during data sampling,
2) nonrandomness of quasar distribution in space,
3) existence of Dopplerian and non-Dopplerian terms in redshifts.

They noted that the effects of spectroscopic selection can influence the observed discretization, but only for an optically selected sample of quasars and not for radioquasars, in which redshift discretization is also observed. Several subsamples of quasars selected using various methods and distributed in opposite directions on the celestial sphere have been analyzed and tested for the question whether selection effects can account for periodicity [30]. Karlsson's formula was:

$$\Delta\ \log{(1+z)} = 0.089$$

which corresponds to:

$$\Delta\ \ln{(1+z)} = 0.206.$$

This equation described correctly the major peaks observed at $z = 0.30$, 0.60, 0.96, 1.41, and 1.96. Their analysis showed that the formula is correct, and the periodicity is not due to selection effects during sample construction. This conclusion is based on totally different methods of subsample construction. Arp et al. wrote, «If the quasar redshifts are caused by the expansion of space and large distances, then the periodicity would violate the cosmological principle that the Universe must look the same from all points within it».

There were several opinions that periodicity in the quasar redshift distribution can be explained only by non-Dopplerian effects, i. e., quasar redshifts are not cosmological. Holba et al. [31] showed that effects of periodicity can be obtained also in the standard FLRW cosmology. The necessary condition is that the periodicity should be much smaller than the considered distance scale.

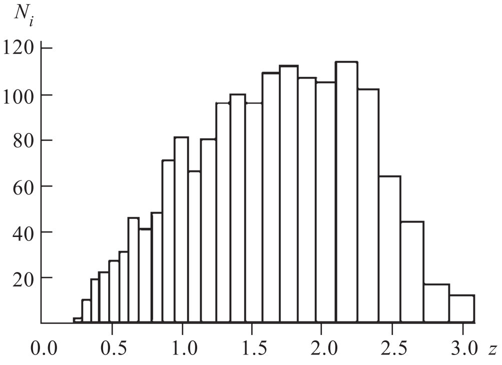

Fig. 4. Distribution of QSO redshifts in Hawkins, Maddox, and Merryfield's sample

Burbidge and Napier [32] took into account new samples of quasars. One of them consisted of 57 high redshift QSO located close ($\leq 10''$) to the low redshift galaxies. In this way, they constructed a sample containing both close galaxy-quasar pairs and multiple QSO's-galaxy structures. At the early stage of their investigation, the search for association between bright low redshift galaxies and quasars was made in order to check noncosmological origin of QSO redshifts. Presently, this method is used to study gravitational lensing. The existence of periodicity in $\log{(1+z)}$ was confirmed, yielding both previously detected maxima as well as some additional ones at $z = 2.63$, 3.45, and 4.47.

2dF QSO Redshift Survey containing over 10000 objects and 2dF Galaxy Redshift Survey with over 100000 galaxies served as an objective basis of periodicity search for quasar-galaxy pairs. The study [33], being a continuation of the above-mentioned paper, was undertaken at Napier's request. Altogether 1647 objects located close (< 200 kpc) to the low redshift galaxies with $z \in (0.1; 0.3)$ were found. Their redshift distributions are presented in Fig. 4.

Some maxima can be observed but according to PSA they are statistically insignificant, which allows one to conclude the lack of statistically significant periodicity in quasar redshift distribution. The result concerns the investigated sample only, i. e., quasars located close (on the celestial sphere) to low-redshift galaxies. It should be stressed here that the statistical significance of periodicity was detected for a sample of quasars selected in such a manner, but the sample was small. Therefore, it is highly probable that all previously detected periodicities are of the same origin; namely, they are due to the smallness of the samples considered. On the other hand, claims that the detected periodicity is due to selection effects were quite correct but probably we have their very complex interactions. In conclusion, the lack of periodicity in quasar redshift distribution leaves no room for new physics.

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