New analysis of the results of the Kholod-80 experiment to search for temperature fluctuations of the background radiation in the angular interval 0.5–6°

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The results of the Kholod-80 experiment, carried out on the RATAN-600, are analyzed by means of a three-point dispersion which does not depend on the distorted low-frequency angular harmonics of the signal of interest. After the noise associated with nonthermal radiation of the local galaxy (with a spectral index of 2.55) is eliminated, and after the noise associated with atmospheric water vapor is eliminated, one can see a correlation signal of unknown nature. This signal has a three-point dispersion with a maximum at a scale of 3.5° and with a dip at 5°. Whether this signal can be attributed to fluctuations of the background radiation is discussed. The relationship between this signal and recent data found by the COBE group is also discussed.

All the attempts which our group has made to detect an anisotropy of the 3-K background radiation at various scales, over the years from 1968 to 1986, are generalized in Ref. 1. Some new results for very small scales (18″–88″) and upper limits on certain harmonics near the scale of the horizon in the recombination epoch were published[2] in 1991. In the present letter we attempt a direct comparison of the data of the deep survey at 7.6 cm which were obtained in 1984 (see Ref. 1) with the predictions of the CDM model for scales smaller than those of the COBE experiment. In this comparison we draw on some results recently published by that group on the anisotropy level at the scale from 7° to a quadrupole.[3]

A resultant Kholod-80 scan (Fig. 1) was constructed from the hourly measurements at 7.6 cm (the most sensitive wave), 31 cm (corresponding to data on galactic noise), and 2.08 cm (corresponding to atmospheric noise). Twenty-two recordings corresponding to good weather were selected. After the scans were averaged over the observations, and after linear drift was eliminated, all the discrete sources observed were subtracted from the 7.6-cm data. A linear combination was then formed with the 31- and 2.08-cm data in order to eliminate the galactic and atmospheric noise. The resultant scan was compressed to 0.5° per pixel.[1]

In order to compare this scan with the large-scale data of the COBE experiment, we had to choose a procedure for a secondary analysis. On the one hand, this analysis would eliminate the distorted large-scale signal, while, on the other, it would lead to a result which could be compared with the theoretical predictions incorporating the COBE quadrupole. For this purpose we used a three-point (Allan) dispersion, in which the contribution from lower multipoles is greatly suppressed:

$$D_A(\Delta\vartheta)=\overline{(T(\vartheta)-[T(\vartheta+\Delta\vartheta)+T(\vartheta-\Delta\vartheta)]/2)^2}. \qquad (1)$$

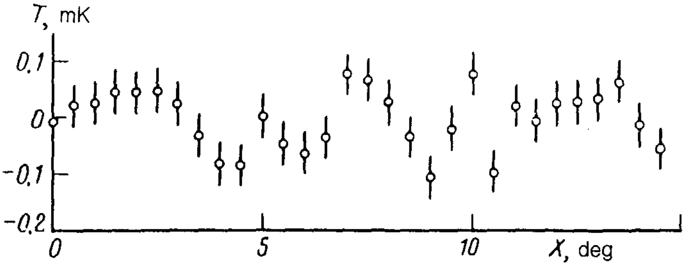

FIG. 1. Resultant data of the deep survey on RATAN-600 ($\lambda=7.6$ cm).

This function, calculated directly from the data in Fig. 1, has a white-noise component $3\sigma_{\rm rec}^2/2$, where $\sigma_{\rm rec}$ is the standard deviation of the noise of the receiver system, which is 39 μK for our accumulation time (see Ref. 1 for more details on the noise of the system). Since we are interested in a correlation signal, this component should be subtracted from each value of $D_A(\Delta\vartheta)$, except the null point. Figure 2 shows the resultant experimental values of D_A for various values of $\Delta\vartheta$.

The three-point dispersion can be expressed in terms of the autocorrelation function of the output data from the radiotelescope:

$$D_A(\Delta\vartheta)=\tfrac{3}{2}C(0)-2C(\Delta\vartheta)+\tfrac{1}{2}C(2\Delta\vartheta). \tag{2}$$

This function can in turn be expressed in terms of the autocorrelation function of the fluctuations of the background radiation, $C_{\rm CMB}$, with the help of the transfer function

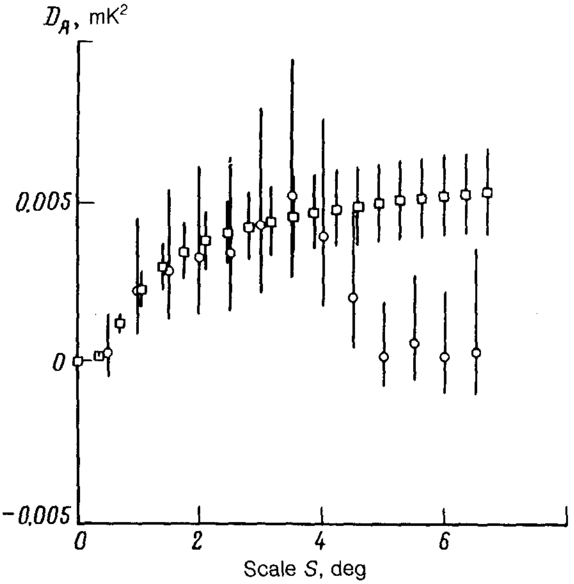

FIG. 2. Three-point dispersion as a function of the angular scale. ○—Experimental; □—theoretical, found with the help of the CDM spectrum, normalized to data of the COBE experiment.

(W) of the rectangular filter used to compress the data and also with the help of the autocorrelation of the directional pattern of the radiotelescope, φ:

$$\tilde{C}(u)=\frac{1}{2\pi}\tilde{W}^2(u)\int_{-\infty}^{\infty}\tilde{\varphi}(u,v)\tilde{C}_{\mathrm{CMB}}(\sqrt{u^2+v^2})dv, \tag{3}$$

where the tilde ($\tilde{\ }$) means a Fourier transform, and u and v are angular frequencies.

According to Refs. 4 and 5, the CDM model with a flat initial spectrum of adiabatic perturbations yields the following expression for the multipole harmonics of the autocorrelation function of the background fluctuations:

$$\tilde{C}_{\mathrm{CMB}}(p)=\frac{A^2T^2}{100\pi}\frac{1}{p^2}\left(1+\frac{0.9p}{l_1}\right)\exp\left(-\frac{p^2}{2l_\Delta^2}\right), \tag{4}$$

$$C_{\mathrm{CMB}}(\vartheta)=\sum_{l=2}^{\infty}\frac{2l+1}{4\pi}\tilde{C}_{\mathrm{CMB}}\left(l+\frac{1}{2}\right)P_l(\cos\vartheta), \tag{5}$$

where $p=l+1/2\gg1$, $A=(4\pm1)\times10^{-4}$, $T=2.74$ K, $l_1=40(H/50)$, and $l_\Delta=450$. Calculations from the exact formulas[4,9] lead to the same result, within 10%.

This value of A corresponds to the COBE quadrupole and falls in the interval $(3\text{–}10)\times10^{-4}$ which was predicted in Ref. 6. This value is furthermore essentially the same as the most recent estimates.[7,8]

Figure 2 shows a theoretical curve of $D_A(\Delta\vartheta)$ for the CDM model with a flat initial spectrum (normalized to the COBE data at $\vartheta>10°$), calculated from Eqs. (2)–(5). The corresponding curve for a model with cold particles, a cosmological constant, and a flat initial spectrum with $\Omega_{\mathrm{tot}}=1$, $\Omega_\Lambda=0.25$, and $H=7.5$ (Refs. 10 and 11, for example) runs about 20% higher. That for the CDM model with an initial spectrum with a step at which the perturbation amplitude triples, at a scale $R=125(50/H)$ Mpc (Ref. 8), runs 10–20% lower.

The experimental curve in Fig. 2 shows that there is a correlation signal. Over the interval up to 4°, this signal may be due to fluctuations of the background radiation in the standard CDM model with a flat initial spectrum [at least at scales $L\gg60(H/50)^{-1}$ Mpc, to which our experiment is sensitive]. There is a dip on the experimental curve at scales of about 5°. This dip could be interpreted as representing the presence of an additional correlation signal (beyond that associated with fluctuations of the background radiation) with a corresponding period [since $C(\vartheta)$ appears in the expression for the three-point dispersion].

Unfortunately, the data in Fig. 1 were prepared only in order to find an upper limit on the anisotropy of the background radiation; the nature of this signal was not studied. This signal might even have been introduced in the course of the data analysis. Furthermore, the following sources of a correlated noise were ignored: the thermal radiation from the local galaxy, effects stemming from the variation in the spectral index of the intense nonthermal radiation of the local galaxy, effects stemming from the variation in the radiation from the earth (these effects vary from one wavelength to another), the variations in the emission of atmospheric oxygen (the 2.08-cm radiometer can measure only the component corresponding to emission by water vapor), and variations in the thermal noise of the waveguides.

If any of these components are important, then our results fall below the predictions of the CMD model with the Harrison–Zel'dovich spectrum, or the COBE data should be interpreted as an upper limit. If this is not the case, then we are seeing a good agreement with the most popular cosmological model (at least at sufficiently large scales) and with the recent results of the COBE group.

On the other hand, if we do not tie ourselves to some specific cosmological model, then the observational curve in Fig. 2 could be interpreted as indicating the presence of a signal with a multipolarity $l=65\pm5$ and a relative amplitude $\Delta T/T=(1.3\pm0.2)\times10^{-5}$ for the case of a harmonic oriented along the scan or $(1.7\pm0.2)\times10^{-5}$ for an isotropic spectrum. Finally, if we assume that the cosmic signal has a Gaussian autocorrelation function $C(\vartheta)/T^2=\sigma_0^2\exp(-\vartheta^2/2\vartheta_c^2)$, if we use the data for $\vartheta=5^\circ$ as an upper limit, and if we assume that there is no special systematic error which reduces the correlation for this scale, we find an upper limit $\sigma_0<1.8\times10^{-5}$ in the interval $1^\circ\leqslant\vartheta_C\leqslant2^\circ$ and $\sigma_0<2\times10^{-5}$ in the broader interval $30'\leqslant\vartheta_C\leqslant3^\circ$, at a confidence level of 90%. This limit is about twice as good as that found in Ref. 12, and it borders on the limit $\sigma_0<1.9\times10^{-5}$ for $\vartheta_C=4^\circ$ reported in a recent paper.[13]

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