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On the Relative Contribution of a Background of Primordial Gravitational Waves to the Angular Fluctuations of the CMB Temperature

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Abstract—A remarkable property of many inflationary scenarios for the early Universe is the generation of a background of primordial gravitational waves, whose contribution to the observed angular fluctuations of the cosmic microwave background (CMB) temperature $\Delta T/T$ is comparable to the contribution from scalar (adiabatic) perturbations. The ratio of the contributions from tensor and scalar perturbations is $T/S \equiv \langle(\Delta T/T)^2_{lm}\rangle_{\rm gw}/\langle(\Delta T/T)^2_{lm}\rangle_{\rm ad} < 1$ for chaotic inflation; it becomes greater than unity for power-law inflation if the slope of the initial-perturbation power spectrum is $n < 0.85$. It is well known that the contributions from adiabatic perturbations and gravitational waves to $\Delta T/T$ are indistinguishable on large ($\theta > 2°$, $l \le 30$) angular scales. It became possible to set an upper limit on T/S only after two independent groups (SK94 and SP94) obtained essentially the same results for $\Delta T/T$ for $l \sim 70 \pm 30$ ($\theta \sim 1°$), because the contribution from gravitational waves decreases considerably on these angular scales. We have numerically calculated $\Delta T/T$ generated by adiabatic perturbations and gravitational waves on angular scales of 10′–2° for chaotic and power-law inflation. By comparing the results of the degree-scale experiments with the COBE data for angles $\theta > 5°$, we have found that $T < S$. Thus, the hypothesis that $T > S$ is not consistent with the available data for $\Delta T/T$ on the degree scale if these data are considered to be fairly representative. On the other hand, $T/S \sim 0.5$, which is expected, for example, in Linde's model of chaotic inflation, is quite acceptable.

INTRODUCTION

With the development of models for the early Universe in the de Sitter (inflationary) stage that has taken place over the past 15 years (Starobinskii 1979, 1980; Guth 1981; Linde 1982, 1983; Albrecht and Steinhardt 1982), it has become possible to explain the previously incomprehensible homogeneity and isotropy of the observable Universe on scales larger than $100h^{-1}$ Mpc (where h is the Hubble constant in fractions of 100 km s^{-1} Mpc^{-1}) and the exceptionally high degree of isotropy of the cosmic microwave background (CMB) ($\Delta T/T \sim 10^{-5}$). The rapidly growing amount of experimental data gives us hope that more subtle details of the structure and origin of the Universe will be elucidated. For example, whereas the Relikt-1 experiment (Klypin *et al.* 1987) made it possible not only to determine the dipole component of the CMB fluctuations and the velocity of the Galaxy, but also to obtain an estimate for the quadrupole component (Strukov *et al.* 1992), the COBE (Smoot *et al.* 1992; Wright *et al.* 1994), KHOLOD (Pariiskii *et al.* 1992), SP89 (Meinhold *et al.* 1993), SP91 (Schuster *et al.* 1993), SP94 (Gundersen *et al.* 1994), and SK94 (Netterfield *et al.* 1995) experiments allow us to estimate the multipoles of $\Delta T/T$ in the range from 2 to 200. In this light, it becomes possible to estimate the potential contribution of primordial gravitational waves to the CMB anisotropy, thereby narrowing the range of viable inflationary models of the Universe.

The large-scale anisotropy in $\Delta T/T$ (for angles $\theta > 2°$) produced by scalar (adiabatic) perturbations with a flat spectrum was calculated by Peebles (1982), Shandarin *et al.* (1983), Starobinskii (1983), and Abbott and Wise (1984), while the isotropy on intermediate angular scales (10′–2°) was calculated by Starobinskii (1987, 1988) and Bond and Efstathiou (1987).

Lifshits (1946) was the first to calculate the evolution of small tensor perturbations in the Friedmann metric. Grishchuk (1974) interpreted the superadiabatic enhancement of gravitational waves (in the case where the wavelength λ is much larger than the cosmological horizon, their amplitude is $h \approx$ const) as the generation of gravitons. Starobinskii (1979) calculated the spectrum of gravitons produced in the inflationary stage. Rubakov *et al.* (1982) were the first to consider the effect of gravitational waves on the CMB anisotropy; they numerically calculated the multipoles with $l = 2, 3$. Subsequently, Starobinskii (1985) analytically calculated multipoles with $l \gg 1$ and concluded that there were inflationary models [namely, chaotic inflation with a power-law inflation potential $V(\phi) \propto \phi^q$] in which $(\Delta T/T)_{\rm gw} \sim (\Delta T/T)_{\rm ad}$, with T/S being independent of l for $2 \ll l \le 30$. It is this lack of dependence of T/S on l that shows that the contribution of gravitational

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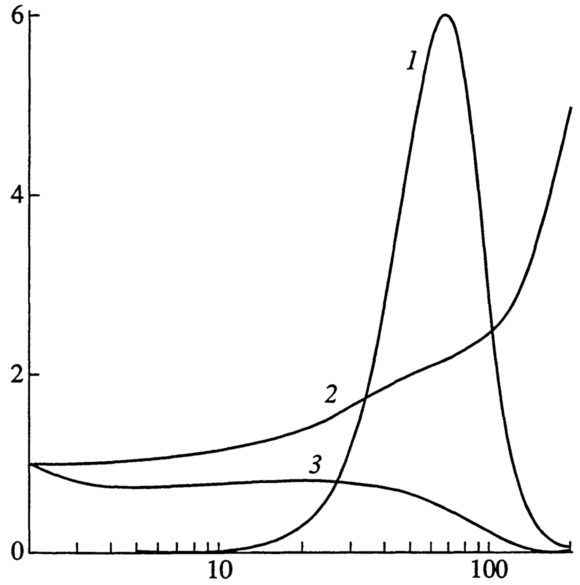

Fig. 1. Window function for the SK94 experiment (*1*) and $C_l l(l+1)/6C_2$ for scalar (2) and tensor (*3*) perturbations in the case of flat spectra and $h_{50} = 1$.

waves to $\Delta T/T$ cannot be distinguished from the contribution of adiabatic perturbations on the basis of the multipole dependence for $l \le 30$. More recently, other inflationary models have been considered, and a hypothesis has been advanced that $T/S > 1$ (Krauss and White 1992; Davis *et al.* 1992; Sahni and Souradeep 1992; Lucchin *et al.* 1992). They are realized in the model of power-law inflation with slope of the perturbation spectrum $n_s < 0.85$.

Various methods have been proposed to determine T/S. The contributions of tensor and scalar perturbations to $\Delta T/T$ on large angular scales can be distinguished by measuring the CMB polarization (Sazhin 1984). Both adiabatic perturbations and gravitational waves contribute to this polarization, but their proportion differs from that for the anisotropy $\Delta T/T$. However, this method requires that the polarization be measured with an accuracy of $\sim 3 \times 10^{-7}$ or higher, which is currently unattainable. Another method is based on the fact that the relative contribution of gravitational waves to $\Delta T/T$ for $l \le 50$ decreases steeply (Starobinskii 1985). Therefore, information on T/S can be obtained by comparing the COBE data with experiments on angular scales of 10′–1°, which is done in this paper. This is illustrated in Fig. 1, where a characteristic window function for a one-degree experiment is also shown. Another variant of this method—comparison of fluctuations for $l \sim 50$ and $l \sim 200$—was proposed by Dodelson *et al.* (1994). In principle, it has a smaller statistical error; however, it cannot be presently implemented in practice due to the absence of sufficiently accurate and representative data for these multipoles. We use the recent SK94 (Netterfield *et al.* 1995) and SP94 (Gundersen *et al.* 1995) experiments as one-degree experiments. In the first of these experiments, the rms temperature fluctuations $\Delta T = 44^{+13}_{-7}$ μK were measured for the interval of multipoles $l = 70 \pm 25$ [a more accurate multipole window for SK94 is given by formula (17) below]. The second experiment yielded $\Delta T = 42^{+16}_{-7}$ μK for $l = 70 \pm 35$. Thus, both experiments gave $\Delta T/T \approx 1.6 \times 10^{-5}$ for $l \sim 70$. Note that this value is in agreement with the result of the KHOLOD experiment (Pariiskii *et al.* 1992). Indeed, as was pointed out by Pariiskii *et al.* (1992), one possible interpretation of the measurements is the detection of a signal with $l = 65 \pm 5$ multipoles and relative amplitude $\Delta T/T = (1.7 \pm 0.2) \times 10^{-5}$ (in the case of an isotropic fluctuation spectrum). The error in the latter formula is a 1σ deviation if the data are fitted by a signal with the above multipoles; errors in individual measurements are considerably larger.

FLUCTUATIONS IN THE CMB TEMPERATURE

In studies of CMB fluctuations, the entire interval of characteristic angular scales is divided into three parts: large angles $\theta \ge Z_{rec}^{-1/2} = 2°$ (scales exceeding the horizon scale at the time of recombination), intermediate angles $10' \le \theta \le 2°$, and small angles $\theta < 10'$ (scales on the order of or shorter than the length characterizing non-instantaneity of recombination). On large and intermediate angular scales, the recombination may be taken to be instantaneous to the first order. The CMB anisotropy in a synchronous reference frame is then given by the formula

$$\frac{\Delta T}{T} = -\frac{1}{2}\int_{\eta_{rec}}^{\eta_0} \frac{\partial h_\alpha^\beta}{\partial \eta} e^\alpha e_\beta d\eta + \left(\frac{1}{4}\left(\frac{\delta\varepsilon}{\varepsilon}\right)_r + v_r^\alpha e_\alpha\right)_{\eta = \eta_{rec}}, \quad (1)$$

where the first and second terms are the contributions from the Sachs–Wolfe and Silk effects, respectively, and the third term is the Doppler shift. The integration is carried out along the light ray with the tangent vector e^α from the time of recombination η_{rec} to the present time η_0 [$\eta = \int dt/a(t)$, where $a(t)$ is the scaling factor of the model under consideration]. In formula (1), $h_\alpha^\beta = -\delta g_{\alpha\beta}/a^2(t)$ is the metric perturbation ($\alpha, \beta = 1, 2, 3$); $(\delta\varepsilon/\varepsilon)_r$ is the energy-density perturbation; and v_r^α is the three-dimensional peculiar velocity of the radiation and the associated baryons. Formula (1) is written for the case in which at the time of recombination $\varepsilon_b \ll \varepsilon_\gamma$ ($\Omega_b \ll 0.1 h_{50}^{-2}$ at the present time, where $h_{50} = H/50$, H is the Hubble constant in km s^{-1} Mpc^{-1}, $\Omega_b = \rho_b/\rho_c$, ρ_b is the baryon density, and $\rho_c = 3H^2/8\pi G$ is the critical density).

In the analysis of CMB fluctuations, it is convenient to expand $\Delta T/T$ in spherical harmonics

$$\frac{\Delta T(\theta,\phi)}{T} = \sum_{l,m}\left(\frac{\Delta T}{T}\right)_{lm} Y_{lm}(\theta,\phi). \quad (2)$$

We introduce the coefficients $a_{lm} \equiv (\Delta T/T)_{lm}$. In what follows, we assume that a_{lm} are Gaussian random variables, as predicted by inflationary models, with

$$\langle a_{lm} a^*_{l'm'} \rangle = C_l \delta_{ll'} \delta_{mm'}, \quad (3)$$

where the angular brackets denote ensemble averaging. The CMB correlation function is then given by the formula

$$\left\langle \frac{\Delta T(0)}{T}\frac{\Delta T(\theta)}{T} \right\rangle = \sum_{l=2}^{\infty} \frac{2l+1}{4\pi} C_l P(\cos\theta), \quad (4)$$

and the contribution from scalar perturbations is

$$C_l^{ad} = (I_1 + I_2)\frac{A^2}{100\pi l(l+1)}, \quad (5)$$

where

$$I_1 = \frac{1}{2(l+1/2)^{\alpha_s}}\int_0^{\infty}\frac{dx(1+4x^2)}{(1+x^2)^{5/2+\alpha_s/2}}(f^2(z)+g^2(z))e^{-(\gamma z)^2},$$

$$I_2 = \frac{1}{2(l+1/2)^{\alpha_s}}$$

$$\times\int_0^{\infty}\frac{dx(1-2x^2)}{(1+x^2)^{5/2+\alpha_s/2}}((f^2(z)-g^2(z))\cos(\theta_{rec} l_1 z)$$

$$-2f(z)g(z)\sin(\theta_{rec} l_1 z))e^{-(\gamma z)^2}.$$

We will use the following analytical approximations for the functions $f(z)$ and $g(z)$ (Starobinskii and Sahni 1984; see also Munshi *et al.* 1995):

$$f(z) = \begin{cases} 1 + 0.042z^2, & z \le 1.55 \\ 0.8991 + 0.1302z, & 1.55 < z \le 9.379 \\ 5z/(z+12.74), & z > 9.379, \end{cases}$$

$$g(z) = \frac{3\ln(1+z/10)}{\sqrt{1+z/16+3z^2/400}},$$

$$z = \frac{l}{l_1}\sqrt{1+x^2},$$

where the quantities l_1, θ_{res}, and α depend on the Hubble constant and matter density (Table 1). The values of I_1 and I_2 are given in the approximation $l \gg 1$; for $l \le 10$ and zero cosmological constant, $I_1 = 1$ and $I_2 = 0$. If the cosmological constant is nonzero and the total energy density is equal to the critical energy density ($\Omega_m + \Omega_\Lambda = 1$), then for $l \le 10$ the quantity I_1 should be multiplied by a correction coefficient on the order of unity arising from the integral part of the Sachs–Wolfe effect and calculated by Kofman and Starobinskii (1985); $I_2 = 0$ as before.

Let us determine A_2 and α_s. The metric fluctuations in a synchronous calibration are expressed in terms of the Lifshits variables $\lambda(k,\eta)$ and $\mu(k,\eta)$. Choosing the calibration $\lambda(k,\eta) \longrightarrow 0$, $\mu(k,\eta) \longrightarrow 3h(\mathbf{k})$ for $\eta \longrightarrow 0$, we then have

$$\langle h(\mathbf{k})h^*(\mathbf{k}')\rangle = \frac{A^2}{k^2(k\eta_0)^{\alpha_s}}, \quad (6)$$

$$h(\mathbf{k}) = \frac{1}{(2\pi)^{3/2}}\int h(\mathbf{r})e^{-i\mathbf{kr}}d^3r,$$

$$\alpha_s = 1 - n_s.$$

For $n_s = 1$, the spectrum is called flat.

The contribution from gravitational waves to $\Delta T/T$ is determined only by the Sachs–Wolfe effect and is given by the formula

$$C_l^{gw} = \frac{B^2}{8}(l-1)l(l+1)(l+2)\frac{1}{\eta_0^{\alpha_g}}\int_0^{\infty}\frac{dk}{k^{1+\alpha_g}}I_l^2(k), \quad (7)$$

where

$$I_l(k) = \int_{\eta_{rec}}^{\eta_0}\frac{J_{l+1/2}(k(\eta_0-\eta))}{(k(\eta_0-\eta))^{5/2}}R_k'(\eta)d\eta$$

and $R_k(\eta)$ is the solution of the equation

$$R_k'' + \frac{2a'}{a}R_k' + k^2 R_k = 0,$$

$$R(0) = 1, \quad R'(0) = 0,$$

which describes the quasi-isotropic mode of the gravitational waves. The quantities B and α_g are defined by the following expressions:

$$h_\beta^\alpha \equiv -\frac{\delta g_{\alpha\beta}}{a^2(t)} = (2\pi)^{-3/2}\int d^3k e^{i\mathbf{kr}} e_\alpha^\beta \frac{B}{k^{(3+\alpha_g)/2}} R_k(t) c_{kj}, \quad (8)$$

$$\langle c_{kj} c^*_{k'j'}\rangle = \delta^{(3)}(\mathbf{k}-\mathbf{k}')\delta_{jj'}.$$

Here, e_α^β is the polarization tensor of the gravitational wave, $e_{\alpha\beta}e^{\alpha\beta} = 1$ for each polarization, and $j = 1$,

Table 1

H	l_1	θ_{res}	γ
50	38.3	0.0211	1/25.4
75	27.4	0.0208	1/44.1

2 means two orthogonal states of polarization. The full quantity C_l is $C_l = C_l^{ad} + C_l^{gw}$, because the gravitational waves and adiabatic perturbations are statistically independent.

MODELS OF INFLATION

Here, we consider two inflationary models: power-law and chaotic inflation.

For power-law inflation, the scaling factor increases as $a(t) \propto t^p$ and the potential is proportional to $\exp(-\lambda\phi/M_p)$. For α_g, α_s, and B/A, we then have

$$\alpha_g = \alpha_s = \frac{2}{p-1} = \alpha, \quad (9)$$

$$\frac{B}{A} = \sqrt{\frac{2}{p}} = \sqrt{\frac{2\alpha}{2+\alpha}}, \quad (10)$$

$$p = \frac{16\pi}{\lambda^2} > 1. \quad (11)$$

For chaotic inflation, we have $V(\phi) \propto \phi^q$, $a(t) \propto \exp(\int H dt)$, and $H = \sqrt{8\pi G V(\phi)/3}$,

$$\alpha_g = \frac{q}{2\ln(k_0/k_f)}, \quad (12)$$

$$\alpha_s = \frac{q+2}{2\ln(k_0/k_f)}, \quad (13)$$

$$\ln(k_0/k_f) \simeq 60 \pm 5,$$

$$\frac{B}{A} = \sqrt{\alpha_g}, \quad (14)$$

where $k_0 = \eta_0^{-1}$, $k_f = \eta_f^{-1}$, and η_f is the time of the end of the inflationary stage in conformal time. Formulas (12) and (13) are written in the approximation $\ln(k_0/k_f) \gg 1$, and their accuracy is ~1%.

The following terminological note should be made. According to Linde, both types of inflation are chaotic, but here, for convenience, we will only call inflation with the potential $V(\phi) \propto \phi^q$ chaotic.

MEASUREMENT OF $\Delta T/T$

The quantity $\Delta T/T$ is measured as follows. Two receivers measure the temperature in two directions with angle θ between them. Since the beam incident on the receiver has a finite width, the window function W_l is introduced to characterize the beam width and the angle θ. The experimentally measured quantity $(\Delta T/T)^2_{sky}$ is given by the formula

$$\left(\frac{\Delta T}{T}\right)^2_{sky} = \sum_l \frac{2l+1}{4\pi} C_l W_l. \quad (15)$$

The function W_l has a maximum near $l \sim 1/\theta$.

For the COBE experiment, the window function takes the form

$$W_l = \exp(-l(l+1)\sigma^2), \quad (16)$$

where $\sigma \simeq 0.0741$. For the SK94 experiment,

$$W_l = \exp(-l(l+1)\sigma^2)\left(\frac{3}{2} - 2P_l(\cos\theta_0) + \frac{1}{2}P_l(\cos 2\theta_0)\right), \quad (17)$$

where $\sigma = 0.0112$ and $\theta_0 = 2.57° = 0.0449$. In the SP94 experiment, W_l is approximately the same but more complicated.

The errors involved in this kind of experiment are rather large; they are associated with the high receiver temperature, emission from the Earth's atmosphere, the Moon, the Sun, and the Galaxy, and other emissions of cosmic origin. The error at the 1σ level is typically ~10%. Apart from the inaccuracy of the experiment, there is another fundamental reason why the experimental data disagree with theory. As was mentioned above, $C_l^{sky} = \langle |a_{lm}^{sky}|^2 \rangle$, where the angular brackets denote ensemble averaging. However, we have only one Universe at our disposal, and, hence, $2l+1$ coefficients a_{lm}. The measured quantity is given by

$$C_l^{sky} = \frac{1}{2l+1}\sum_m |a_{lm}^{sky}|^2, \quad (18)$$

and its rms fluctuation is

$$\left\langle (C_l^{sky} - C_l)^2 \right\rangle = \frac{C_l^2}{l+1/2}. \quad (19)$$

The uncertainty of the experiment arising from the uniqueness of our Universe is then equal to

$$\left\langle \left(\left(\frac{\Delta T}{T}\right)^2_{sky} - \left\langle \left(\frac{\Delta T}{T}\right)^2 \right\rangle\right)^2 \right\rangle = 2\sum_l \frac{2l+1}{(4\pi)^2} C_l^2 W_l^2. \quad (20)$$

Presently, reliable data are available for angles of the order of 10° (COBE) and 1° (SP94, SK94). The COBE results are normalized to $Q \equiv T_\gamma C_2$ assuming that there are no tensor perturbations and using the formula for scalar perturbations with a flat spectrum for $I_1 = 1$ and $I_2 = 0$:

$$\left\langle \left(\frac{\Delta T}{T}\right)^2_{lm} \right\rangle_{ad} = \frac{A^2}{100\pi l(l+1)}. \quad (21)$$

Although the results are given for C_2, in the calculations they should be recalculated for C_9. The SK94 results are presented as ΔT, where $\Delta T/T$ is defined by formula (15) with the window function (17).

CALCULATION OF T/S

Figure 1 shows that the behavior of C_l^{ad} for $l > 30$ begins to differ markedly from that of C_l^{gw}. The results of numerical calculations of C_l^{gw} for various values of α_g are presented in Fig. 2 for $h_{50} = 1$ and in Fig. 3 for $h_{50} = 1.5$. The results of similar calculations for C_l^{ad} are presented in Figs. 4 and 5, respectively. Note that $h_{50} = 1.5$ requires a nonzero cosmological constant (due mainly to the age of the Universe), which was taken to be $\Omega_\Lambda = 1 - \Omega_m = 0.75$. In Fig. 5, we did not allow for the above correction factor to C_l^{ad} for $l < 10$, which results from the integral term in the Sachs–Wolfe formula being nonzero for $\Omega_\Lambda \neq 0$. The corresponding correction to C_l^{gw} is small for $l > 2$ (Panteo and Starobinskii 1995).

The available data cover the scales $2 \leq l \leq 30$ (COBE) and $50 \leq l \leq 90$ (SP94, SK94). Consequently, we can try to extract information about A^2 and B^2 from these data. Let us denote the result calculated for C_9 from the COBE data by R_{COBE}. Here, we will use the results of Gorski *et al.* (1994) obtained from an analysis of the two-year COBE data. Assuming $T_{COBE} \equiv \frac{C_9^{ad}}{A^2}$ and $S_{COBE} \equiv \frac{C_9^{gw}}{B^2}$, we have

$$A^2 S_{COBE} + B^2 T_{COBE} = R_{COBE}. \tag{22}$$

For the second experiment (SK94), we calculate R_{SK} from formula (15) with the window function (17) and $C_l = C_l^{ad} + C_l^{gw}$ from formulas (5) and (7). Denoting

$$S_{SK} = \frac{1}{A^2}\sum_l \frac{2l+1}{4\pi} W_l C_l^{ad},$$

$$T_{SK} = \frac{1}{B^2}\sum_l \frac{2l+1}{4\pi} W_l C_l^{gw},$$

we have for R_{SK} measured in the experiment

$$A^2 S_{SK} + B^2 T_{SK} = R_{SK}. \tag{23}$$

Solving the system of linear equations (22) and (23), we obtain A^2 and B^2.

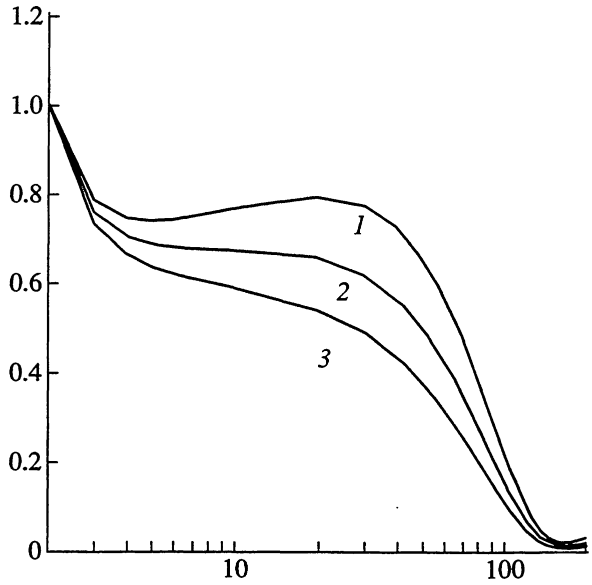

Fig. 2. $C_l^{gw} l(l+1)/6C_2^{gw}$ for $h_{50} = 1$ and $\alpha_g = 0$ (*1*), 0.1 (*2*), and 0.2 (*3*).

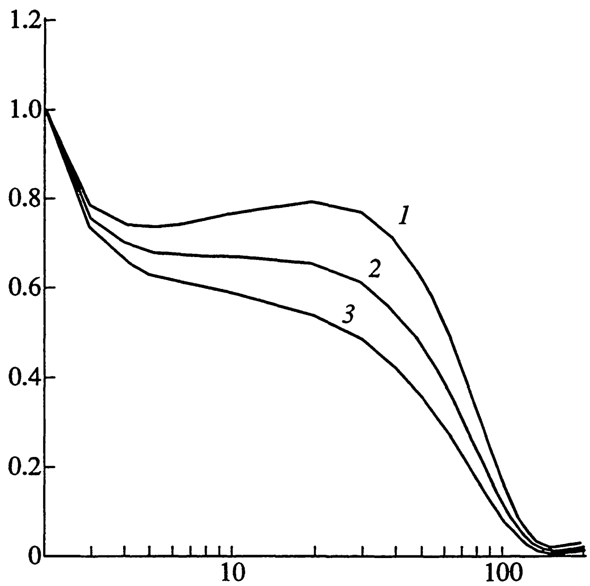

Fig. 3. Same as in Fig. 2, but for $h_{50} = 1.5$ and $\Omega_\Lambda = 0.75$.

RESULTS AND CONCLUSION

We performed all our calculations for the two-component matter–radiation model for a flat Universe. For $H = 50$ km s^{-1} Mpc^{-1}, we set the cosmological constant equal to zero; for $H = 75$ km s^{-1} Mpc^{-1}1, we took $\Omega_\Lambda = 1 - \Omega_m = 0.75$. The radiation density included the contribution from three types of massless neutrinos.

The results of our calculations for the flat spectra of tensor and scalar perturbations, $\alpha_g = \alpha_s = 0$, are summarized in Table 2; here, we do not assume any specific

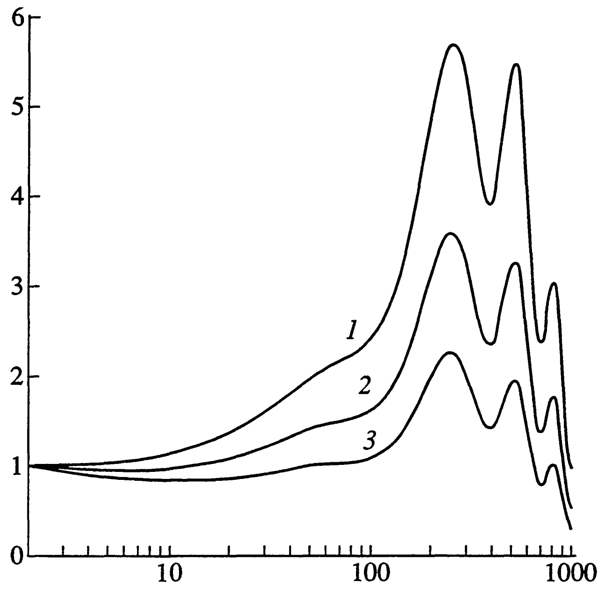

Fig. 4. Same as in Fig. 2, but for $C_l^{ad} l(l+1)/6C_2^{ad}$.

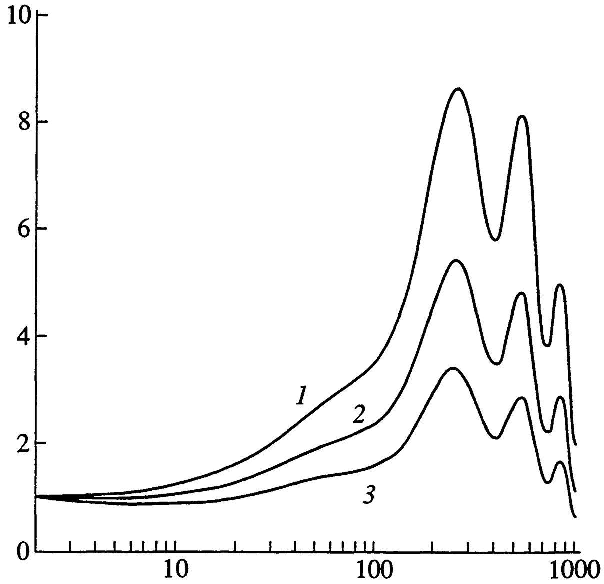

Fig. 5. Same as in Fig. 4, but for $h_{50} = 1.5$ and $\Omega_\Lambda = 0.75$.

inflationary model. The notation in the table has the following meaning: $(B^2/A^2)_w$ is the most probable value of B^2/A^2; $B^2/A^2 < (B^2/A^2)_1$ with a probability of 84%, and $B^2/A^2 < (B^2/A^2)_2$ with a probability of 97.5%.

The results for power-law and chaotic inflation are given in Tables 3 and 4, respectively [in these cases, B^2/A^2, α_g, and α_s are related to the inflation parameters by formulas (9)–(14), and the notation has the same meaning as in Table 2].

In order to obtain the commonly used value of T/S, B^2/A^2 should be multiplied by a factor ≈ 5.3 for $l \approx 10$ [see Polarski and Starobinskii (1995) for a more detailed discussion of this problem]. Hence the radical hypothesis that $T > S$ is essentially ruled out for actual inflationary models. We have previously published this result in a brief form (Markevich and Starobinskii 1995). On the other hand, a more conservative value of $T/S \approx 0.5$, which, as was shown by one of us (Starobinskii 1985), obtains in Linde's model of chaotic inflation with the inflation potential $V(\phi) \propto \phi^4$ (Linde 1983), remains quite feasible.

Table 2

H	$(B^2/A^2)_w$	$(B^2/A^2)_1$	$(B^2/A^2)_2$
50	0.02	0.17	0.42
75	0.13	0.50	0.69

Table 3

H	$(B^2/A^2)_w$	$(B^2/A^2)_1$	$(B^2/A^2)_2$
50	0.01	0.07	0.13
75	0.06	0.13	0.18

Table 4

H	$(B^2/A^2)_w$	$(B^2/A^2)_1$	$(B^2/A^2)_2$
50	0.004	0.07	0.13
75	0.06	0.12	0.18

Note that we took into account the statistical error associated with the deviation of a random realization of $\Delta T/T$ in our Universe from ensemble means (cosmic variance) only for the COBE experiment, and not for the SK94 and SP94 experiments, which cover only a small part of the sky. This is tantamount to assuming that those regions of the sky that were surveyed in these experiments are not atypical (more specifically, they are not regions of rare maxima of $\Delta T/T$). The fact that the results of both experiments are in close agreement even though widely separated regions were studied strongly suggests that this assumption is valid. Of course, in order to ultimately confirm our conclusions, a survey of a significant part of the sky with angular resolution θ_{FWHM} no worse than 0.5° would be needed.

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