L. P. Grishchuk. *The problem of relic gravitational radiation.* Noise-type gravitational radiation is incident on the earth in addition to monochromatic and pulsed radiation of cosmic origin. Relic gravitational waves, (cosmic gravitational background radiation), which have existed since the time at which the Metagalxy was in a superdense state, are an important type of this radiation. Formation of relic gravitational radiation with a nonthermal spectrum is predicted by a gravity-wave amplification mechanism with spontaneous production of gravitons in the strong gravitational field of the early Universe. (A discussion of the basic principles and results, together with references to earlier works, will be found in Refs. 1 and 2). This mechanism works even within the framework of elementary assumptions as to the structure of the nonstationary field of the early Universe, namely when it is assumed to have been completely homogeneous and isotropic. In this respect, gravitons differ cardinally from other particles (neutrinos, photons, gravitinos), which are not produced in a homogeneous isotropic gravitational field. More complex structures of the gravitational field of the early Universe do not change the graviton-production effect, but drawing theoretical conclusions concerning the results of this process under various sets of initial conditions becomes more difficult and less definite. The assumption that the gravitational field of the early Universe was homogeneous and isotropic (accurate to within small corrections) is not only the simplest possible assumption, but also consistent with available observations, a consequence of the validity of Friedman models for description of the entire known range of cosmological data.

The relic gravitational radiation is formed as a result of effective amplification of vacuum fluctuations of the gravitational field during the time of so-called "Planckian" densities of matter and intensities of the external gravitational field. The spectrum of the gravitons produced should remain practically unchanged right up to the present, since the cross sections of processes in which gravitons participate are so small[3,4] that there is apparently no sufficient time for thermalization of nonequilibrium gravitons.

The present energy density of the relic gravitational radiation and the form of its spectrum depend on the rate of change of the strong gravitational field of the early Universe. If there were, in the initial state and in addition to vacuum fluctuations, also gravity waves left over, for example, from the time of the preceeding hypothetical contradiction, they would also be subject to amplification and would contribute to the present characteristics of the background radiation. The most conservative (and plausible) hypotheses as to the nature of the gravitational field of the early Universe lead to the conclusion that there now exists an isotropic gravitational wave background with a power-law spectrum in the frequency range from $\nu_m \approx 10^{-8}$ Hz to $\nu_c \approx 10^{11}$ Hz and with a total energy density ε_g of the order of the energy density of the equilibrium three-degree electromagnetic background ε_γ. The models that predict a maximum of the spectrum at high rather than low frequencies appear more probable. In extreme cases, the prediction is that $\varepsilon_g \ll \varepsilon_\gamma$ or $\varepsilon_g \gg \varepsilon_\gamma$. Detection of relic gravitational radiation with some particular energy density and spectrum shape would make it possible to draw rather confident inferences as to the nature of the physical processes at extremely early stages in the evolution of the Universe.

In addition to the relic gravitational radiation, other forms of stochastic gravity-wave background also exist. They are formed by a multitude of various, simultaneously operating, discrete and extended sources of monochromatic and pulsed radiation.[5] Knowledge of their total intensity and spectrum shape would be necessary even just to indicate the frequency ranges in which the relic radiation might be dominant. Comparison of existing calculations indicates that there are broad frequency bands at both high and low frequencies in which the relic background is, in principle, accessible to observation.

Let us make a rough estimate of possibilities of detecting the relic background. Let us assume that the background takes the form of a broad spectrum with a width of the order of some average frequency ν_0. We shall assume the total energy density equal to $\varepsilon_g \approx 10^{-12}$ erg/cm^3. Different values of the characteristic dimensionless amplitude of the metric h correspond to different choices of ν_0 at a given value of ε_g. Different ν_g call for different optimum observing methods. Let us consider a few cases.

1) $\nu_0 \approx 10^{-8}$ Hz, $h = 10^{-12}$. Reduction of many years of pulsar observations indicates that even the quietest among them are subject to pulse-frequency variations that could have been acquired on passage through a stochastic gravity-wave background with precisely the characteristics indicated.[6] More thorough investigations should show whether we are dealing with an effect of a gravity-wave background or with noise of another nature.

2) $\nu_0 \approx 10^{-3}$ Hz, $h = 10^{-17}$. Doppler tracking of spacecraft velocities is promising. We are now capable of registering frequency variations at the level $\Delta\omega/\omega \approx 10^{-15}-10^{-16}$, while the expected effect is $\Delta\omega/\omega \approx 10^{-17}$⊙ 3) $\nu_0 \approx 10^4$ Hz, $h = 10^{-24}$. Gravitational noise with such characteristics could be registered with mechanical antennas having the following parameters: $m = 10^6$ g, $l = 10^2$ cm, $Q = 10^9$, $T = 10^{-4}$ K, total observing time $\hat{\tau} \approx 1$ yr. 4) $\nu_0 \approx 5 \cdot 10^6$ Hz, $h = 2 \cdot 10^{-27}$. The following parameters should be attainable with electromagnetic resonators: $l = 3 \cdot 10^3$ cm, $H = 10^5$ G, $Q = 10^{13}$, $T \approx 3 \cdot 10^{-4}$ K with an observing time $\hat{\tau} \approx 10^6$ sec. 5) $\nu_0 \approx 10^{10}$ Hz, $h = 10^{-30}$. A multiple-reflection laser interferometer might be suitable, but the best contemporary systems are probably capable of sensitivity limits 4–5 orders of magnitude lower than what is needed.

The above estimates indicate that it will be extremely difficult to detect the relic gravitational background. However, it may be hoped that the prospect of obtaining scientific information of fundamental importance will stimulate exploration and the development of the required systems.

[1]L. P. Grishchuk, Usp. Fiz. Nauk 121, 629 (1977) [Sov. Phys. Usp. 20, 319 (1977)].

[2]L. P. Grishchuk and A. C. Polnarev, In: Einstein Century volume Ed. A. Held. Vol. II, Plenum Press, 1980, p. 393.

[3]Ya. B. Zel'dovich and I. D. Novikov, Stroenie i évolyutsiya Vselennoĭ (The structure and Evolution of the Universe). Nauka, Moscow, 1975.

[4]I. Yu. Kobzarev and P. I. Peshkov, Zh. Eksp. Teor. Fiz. 67, 428 (1974) [Sov. Phys. JETP 40, 213 (1975)].

[5]B. J. Carr, Caltech Preprint OAP N 566. July 1979.

[6]M. Demyanskiĭ and M. V. Sazhin, Nature (in press).