LARGE-SCALE ANISOTROPY OF THE COSMIC RELIC RADIATION IN SPATIALLY OPEN COSMOLOGICAL MODELS

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The observed microwave background radiation is a sensitive tool for studying the fundamental features of the universe. A puzzling constancy on the celestial sphere of the temperature, T, of the equilibrium relic radiation coming to us from causally nonrelated regions of space-time points to the global spatial homogeneity and isotropy of the cosmological expansion. On the other hand, a small anisotropy of the relic background can tell a lot about the physics of the beginning of the universal expansion, where primordial cosmological perturbations, which later affect the relic isotropy, formed (see, e.g., [1,2] and other reviews on the early universe). We would like to emphasize another factor that forms mainly the large-scale structure of relic anisotropy: the spatial curvature of the background Friedmann Universe. In the light of the discovery of the large-scale anisotropy of the cosmic radiation [3-5], this problem becomes very important.

Let us consider the observable structure of the largest-scale perturbations in the spatially flat, closed and open cosmological models. Quantitatively, the space curvature within the present cosmological horizon is characterized by Ω, the ratio of the mean-to-critical density.

It is well known that any small perturbations of infinite scale in the flat background model do not disturb spatial curvature and the space deformation they cause results in a quadrupole anisotropy of the relic temperature ($\Delta T/T$). These infinite-scale perturbations are spatially homogeneous (they belong to the Bianchi Type I cosmological models) and any of their linear superpositions has the same properties [6-8]. The largest possible scale perturbations of the closed Friedmann model disturb the cosmic radiation in a similar manner: the characteristic angular scale of the temperature variations is of the order of unity and, in this sense, the T/T structure is qualitatively the same for $\Omega - 1$ and $\Omega > 1$. (Subtler differences may be revealed after measurements of the following low-order moments of the relic background and taking into account the discrete spectrum of perturbations in the closed space.)

A qualitatively new effect appears in the open background model with the Lobachevski hyperbolic 3-space [9]. The simplest infinite-scale perturbation mode does not disturb spatial curvature, it is spatially homogeneous (Biachi Type V) and deforms the space along a bundle of

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parallel lines [7]. Figure 1 demonstrates the principal directions of the shear deformation in the 2-plane to which the line going through the observer (in the center) belongs. Relic quanta propagate to the observer along the radii, the circle is the locus of the last scattering of relic photons (its inverse radius $\simeq \Omega$ for $\Omega \ll 1$). Figure 2 shows the relic temperature anisotropy caused by this homogeneous mode. The radius is the temperature in the given direction (dashed and solid curves correspond to $\Omega \simeq 1$ and 1/3, respectively). Thus, with Ω decreasing, the quadrupole $\Delta T/T$ transforms to the ring (spot) with angular dimension $\Delta\Theta \simeq 2\Omega$ [9,10]. Arbitrary infinite-scale perturbations are linear superpositons of the homogeneous modes considered, so large-scale relic anisotropies in the open universe have characteristic angular variations of temperature $\sim \Omega$ [7,8]. The relic spot-anisotropy caused by large-scale perturbations is as natural a property of the Lobachevski space as is the quadrupole for the Euclidean one.

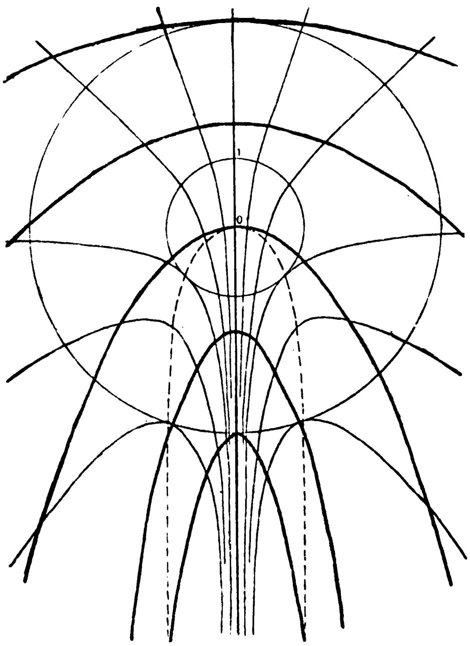

Figure 1

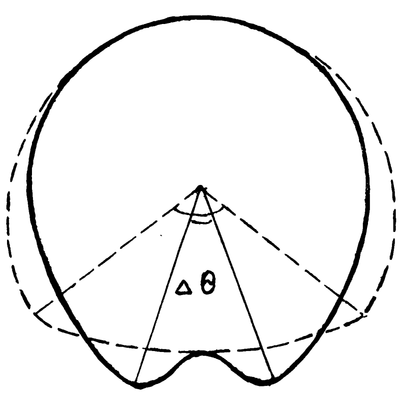

Figure 2

Next, we consider the technique of detecting this effect on the celestial sphere. The Lifshitz formalism of spherical harmonics [11] is good for flat and closed spaces (see, e.g., [12,13], etc.), but not for the hyperbolic one. The point is that the infinite-scale homogeneous perturbation, which is constant over the Lobachevski space and gives the $\Delta T/T$-spot, has a wide spectrum of all-order moments while being expanded on spherical harmonics. (Note that the harmonics with a characteristic variation of $\Delta\Theta \sim \Omega$ will be slightly singled our [14]; in the Euclidean case only a quadrupole moment does not vanish.) That is why, in order to single out the pure spot-effect, it is necessary to use the formalism of parabolic waves, which form a full set of eigenfunctions in the Fourier-integral expansion and are analogs of plane waves in the Lobachevski space [7,8]. Each of these waves gives the $\Delta T/T$ spot with its microstructure depending on the wavenumber K. For example, the scalar convergent and divergent parabolic waves have the form:

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$$Q^{\pm} = (\sqrt{1 + h^2\vec{x}^2} \mp h\vec{e}\vec{x})^{\mp ik/h}, \quad k \gtrsim 0 ,$$

in the space coordinates $d\ell^2 = dx^2 + dy^2 + dz^2 - (h\vec{x}d\vec{x})^2/(1 + h^2\vec{x}^2)$, where $\vec{e}$ is the unit vector in the direction of the wave propagation. Evidently, $Q^{\pm} = e^{i\vec{k}\vec{x}}$ for $h = 0$ (Euclidean space) and the spot scale $\Delta\Theta \simeq 2|\vec{x}_{last\ sct}|^{-1} \simeq 2\Omega << 1$ for $h = 1$ (Lobachevski space); $\vec{k} = k\vec{e}$, $\vec{e}\vec{x} = |\vec{x}| \cos \Theta$.

References

1. Lukash, V.N. Novikov, I.D. Proceedings of I.A.U. Symposium 104, (1983), p. 457. Aug. 30 to Sept. 2, 1982.
2. Lazarides, G. Proceedings of I.A.U. Symposium 104, Crete, Greece, (1983), p. 469.
3. Smoot, G.F., Lubin, P.M. Ap. J., 234, L83, 1979.
4. Fabbri, R., Guidi, I., Melchiori, F., Natal, V. Preprint, 1979.
5. Boughn, S.P., Cheng, E.S., Wilkinson, D.T. Ap. J., 243, L113, 1981.
6. Lukash, V.N. Nuovo Cimento, 35 B, 268, 1976.
7. Lukash, V.N. Proceedings of the Eighth International Conference on Gravitation, 237, Waterloo, Canada, 1977.
8. Bisnovatyi-Kogan, G.S., Lukash, V.N., Novikov, I.D. Proceedings of Fifth Regional Meeting (IAU/EPS), Liège, Belgium, 29 to 31 July 1980.
9. Novikov, I.D. A. Zh., 45, 538, 1968.
10. Doroshkevich, A.G., Lukash, V.N., Novikov, I.D. A. Zh., 51, 940, 1974.
11. Lifshitz, E.M. Zh.E.T.F., 16, 587, 1946.
12. Grishchuk, L.P., Zeldovich, Ya.B. A. Zh., 55, 209, 1978.
13. Silk, J., Wilson, M.L. Ap. J., 244, L37, 1981.
14. Wilson, M.L. Ap. J., 253, L53, 1982.

Discussion

Smoot: Novikov visited Berkeley about four years ago and pointed out that a quadrupole anisotropy in expansion would give a large-scale anisotropy of the spot shape in the cosmic background radiation. A graduate student, Chris Wilebsky, and I read his paper and used a small dish antenna to search for such an effect near the maximum in the dipole anisotropy measured by our U2 experiment. Since that time the bulk of the dipole signal is better explored and is accepted as due mainly to the motion of the galaxy. Thus, you make a very valid point that fitting by using spherical harmonics does not efficiently search for these spot size anisotropies. Although we make maps now that the receivers are so improved, using your parabolic wave expansion will provide a much better qualitative limit. For $\Omega \lesssim 0.05$ the antenna beam size will smear the spot significantly from its characteristic shape which Chris and I referred to as the "Navel of the Universe" because of the shape like a navel orange and its signature as a relic of the birth of the universe.

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Lukash: I would like to note that the search for the spot anisotropy must differ from that for the dipole one. The point is that you can, in principle, detect the dipole while investigating any region on the celestial sphere of an angular scale ~ 1. But if the actual anisotropy is of the spot type (even with the characteristic angular scale ~ 1 for $\Omega \sim 1$!), then, for example, you find nothing in the southern sky and detect the spot only in the northern sky.

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