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TOWARDS A NON-FRIEDMANNIAN UNIVERSE

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SUMMARY

We present the result of an experiment of the Florence group which has detected a quadrupole anisotropy in the cosmic background radiation. We show that this result implies that the Universe either has large metric perturbations outside the particle horizon, or will become largely irregular in the future.

Although theoretical cosmologists have explored the properties of cosmological models endowed with anisotropies and inhomogeneities, nevertheless it is widely believed that the actual universe is homogeneous and isotropic at large scales, so that any global model should be Friedmannian in order to be possibly related to physical reality. Theoretical arguments also have been proposed to support this belief (1). However it is hardly deniable that the main reason for this attitude is that an arbitrarily irregular universe would lack the beauty and simplicity of the isotropic universe. This may be considered as a remnant of the Ptolemaic view of the Cosmos and gratifies our instinctive expectation that the world would respect the human wish for beauty and simplicity. However one should relinquish any residual anthropocentrism and leave any decision to experiment. Unfortunately, classical astronomical tests on the large-scale structure of the universe are not very sensitive.

A powerful tool for solving the issue of the global properties of the universe is the investigation of the angular distribution of the cosmic background radiation (CBR) discovered by Penzias and Wilson (2). Fluctuations of the radiation temperature have been sought at many angular scales. At scales $\alpha = 1'-2°$ the radiation has been found to be isotropic up to a few parts over 10^4 (3). However, in order to get information on the cosmic structure we should look for temperature anisotropies of the CBR at larger angular scales. Perhaps the first piece of observational evidence for a non-Friedmannian universe is provided by the recent experiments of the Princeton and Berkeley groups (4,5) who detected a dipole (i.e. first harmonic) anisotropy $\Delta T/T = 1 \times 10^{-3}$. This result might imply (together with optical data) that a large aggregate of matter comprising the Local Group and the Virgo Cluster is moving at a speed of $\simeq$ 600 km/sec relative to the CBR frame of reference. However, it is more likely to be explained by the dynamics of the Local Supercluster (6) as pointed out by White and Silk (7). Although the existence of structure over tens of Megaparsecs is a further blow to our expectation for a quite symmetric Universe, we recognize that such a scale length is small in comparison with the conventional radius of the universe $c/H_0 \simeq 5000$ Mpc, or the particle horizon $2c/H_0$. In order to attribute a certain cosmological origin to the CBR anisotropy, it should be quadrupole-type , i.e. should be described by some second-order harmonic. A "local" phenomenon (say, on the Local Supercluster scale or less) can produce a dipole anisotropy but not a quadrupole one. The clue to the detection of higher-order anisotropies in the CBR is the use of infrared detectors operating in the millimetric wavelength region, which have a higher sensitivity than the standard radio systems. In July 1978 a balloon-borne infrared "isotropometer" was flown by our group (8) and measured the CBR anisotropies in the 500-2000 μm band. Our instrument was capable of reaching an ultimate sensitivity $\Delta T/T = 2\times10^{-5}$. Another important feature of the experiment was the use of a wobbling mirror scanning spots only 6° apart in the sky. So the temperature gradient is actually measured, and anisotropy components at angular scale α appear as magnified by a factor $2\pi/\alpha$ with respect to the dipole term. The main results of the experiment are reported in Figure 1. A quadrupole term of amplitude Q = 0.9 mK clearly appears, about 15 standard deviations above the noise level. This result implies the existence of cosmic structure with length scale $\gtrsim c/H_0$ and metric fluctuations $\geq 3\times10^{-4}$. The experiment excludes the existence of perturbations with comparable intensity at scales $L \gg 100$Mpc but still smaller than the radius of the universe; in addition to the dipole anisotropy D = 3 mK, perturbations at such scales give fluctuations with $2° < \alpha < 180°$ with amplitude $10^{-3}\ LH_0/2c$. Since the sensitivity to higher harmonics is $\propto 2c/LH_0$ we should detect fluctuations of order 10^{-3} at $\alpha \geq 6°$, which instead are absent. (A previous experiment (9) excludes fluctuations of this order of magnitude at scales down to 2°). Several results can be inferred. If the global topology is closed, the detected quadrupole implies that some irregularity of order 10^{-3} extends all over the universe. If the universe is open but the perturbation arises from homogeneous anisotropy (10) the situation is nearly the same as for the closed topology; if on the other hand we have an inhomogeneous fluctuation of length scale L finite, the maximum amplitude of the metric perturbation (not detectable today since it is outside the horizon) is $\sim 10^{-3}(LH_0/c)^2$, and may be of order unity provided $L \sim 10^5$Mpc.

In order to prove these statements, we begin observing that in any case the past history of the perturbation within the horizon is described well by some anisotropic homogeneous model (a Bianchi space (11)). In analogy with density waves (12), two modes of homogeneous anisotropy exist, one of which decreases monotonically during the expansion and is strongly affected by dissipative mechanisms (13,14). Extensive calculations in most general Bianchi spaces (5) have shown that, due to neutrino viscosity operating at time $t \lesssim 1$ sec., this mode has amplitude $\lesssim 10^{-6}$ at redshift $z = 10^{3}$. A further mechanism, i.e. particle creation near the Planck time $t \sim 10^{-43}$ sec, is very effective in removing the primordial anisotropy (14), and other mechanisms might operate at early times. So we exclude that the detected anisotropy is due to this mode, and we must resort to the other one which is driven by curvature anisotropies and is little affected by dissipation. For this mode the anisotropy of the Hubble expansion the present epoch is $\Delta H/H_{\circ} \simeq (\Delta T/T)_{Q}$. If the perturbation appears outside the horizon as a density or a gravitational wave, the metric perturbation is in both cases given by $\sim(\Delta H/H_{\circ})(H_{\circ}L/c)^{2}$. A vortex motion on scale $\gtrsim c/H_{\circ}$ should be excluded as a source of the quadrupole anisotropy, since it would give trouble for the primordial formation of elements.

We can conclude that the metric perturbation superposed on the Friedmann background is certainly greater than $\sim 3\times 10^{-4}$, and may be much larger. It is important to notice also that it cannot decrease in the future. As a matter of facts, the curvature-driven mode cannot be damped in the future evolution, whether or not the perturbation scale falls within the particle horizon eventually. If the universe has a low matter density the perturbation amplitude will remain nearly constant for an exceedingly long time. But is $\Omega_{\circ}$ is very close to unity the perturbation will grow like $t^{2/3}$, so it will certainly become of order unity within 10^{18}y (cf. also ref. (10,15,16)); this stage will be reached much earlier than that if the universe is closed (possibly within a few tens of billion years).

We conclude that even if the universe looks very smooth and symmetric today, it will become extremely irregular sooner or later, and perhaps it is such just now at sufficiently large scales.

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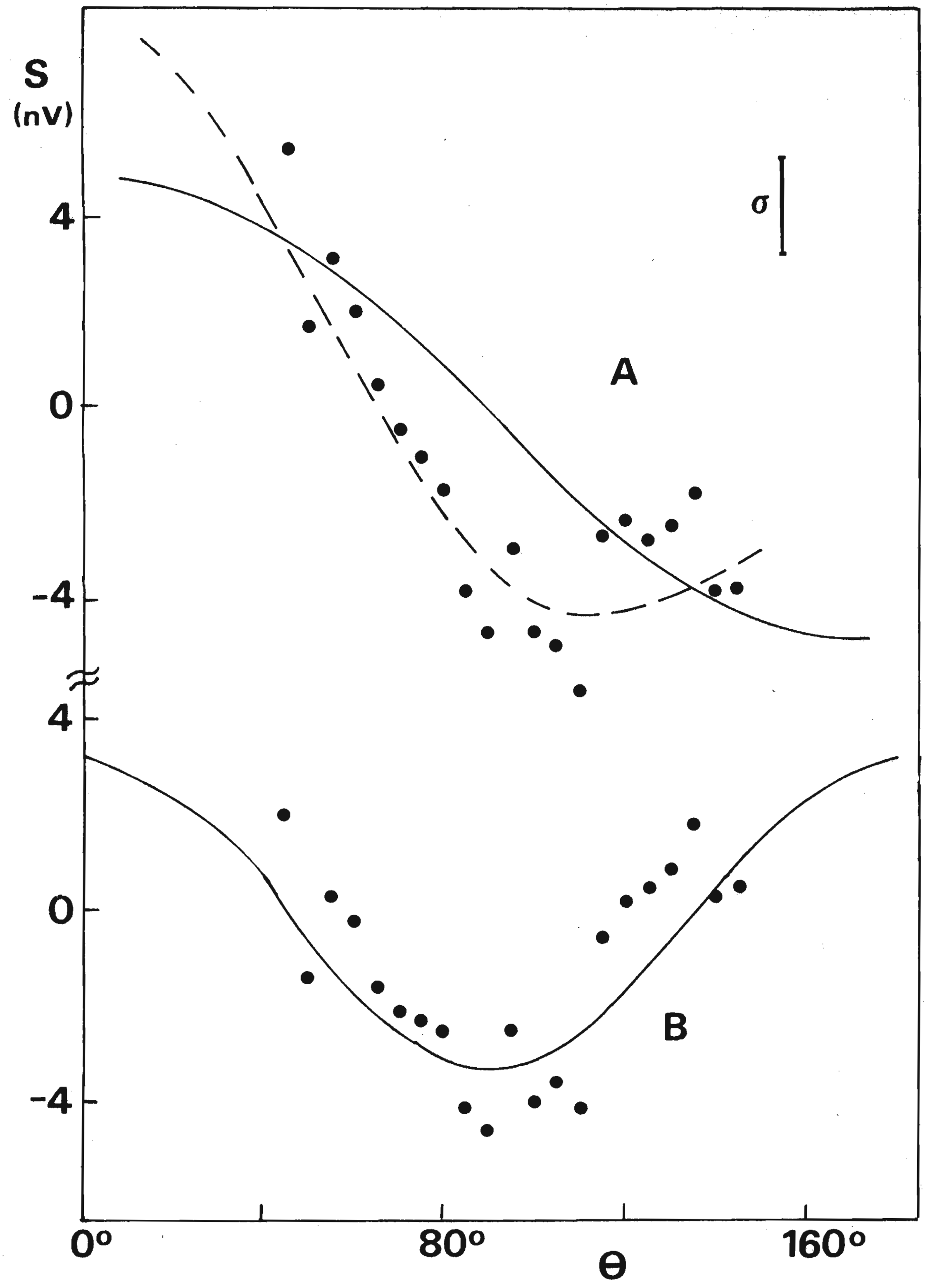
FIGURE CAPTIONS

Figure 1. Sky anisotropy in the millimetric region, as measured by the Florence Group. θ is the angle between the direction of modulation in the sky and the direction of maximum anisotropy. (A) The full line represents a pure cosine fitting of the data averaged over 5°. The dashed line is the final fitting including the quadrupole term. (B) Data after subtraction of the fitting dipole and best fitting quadrupole.



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