NEW MEASUREMENTS OF THE COSMIC BACKGROUND RADIATION SPECTRUM

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Summary. – We have continued our program to measure the long-wavelength spectrum of the cosmic background radiation. Our previous observations were at five wavelengths – 0.33, 0.9, 3.0, 6.3, and 12.0 cm – and had a weighted average value of 2.73 ± 0.05 K and deviated from a Planckian spectrum by less than 6%. In August 1984, we repeated our observations at 3.0, 0.9, and 0.33 cm and made new observations with a radiometer tunable from 1.7 to 15 cm. Preliminary analysis indicate that the new data are consistent with our previous results.

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1. – INTRODUCTION

The Cosmic Background Radiation (CBR) is one of the few observables that retains information about the early universe, but there are limits to its memory. In the standard Big Bang model the universe is opaque at redshifts z greater than about 1000. For times after $z \approx 1000$ the matter in the universe is mostly in neutral atoms and the optical depth (due primarily to Rayleigh scattering) is much longer than the present Hubble radius (10^{10} light years). Before a redshift of 1000 the matter is in the form of primordial plasma, because the temperature is greater than 3000 K so that the hydrogen and helium are ionized. Just before this boundary the primary interaction between the CBR and matter is through Compton (Thomson) scattering of the photons by free electrons. The angular distribution for low-energy Compton scattering is nearly isotropic so that directional information is practically erased by a single scattering. Polarization information is lost nearly as quickly. Before recombination ($1000 < z < 1500$) the universe and its contents are obscured by a cosmic fog bank. Objects in the foreground, such as stars, galaxies, and quasars, can be imaged conventionally and clearly. Objects in the boundary are hazy and ill-defined. Objects in the background before the boundary are obscured and hidden from view. The angular distribution of the CBR thus carries information on the large-scale structure of the universe and the inhomogeneities in the matter distribution at the surface of last scattering. Earlier information is lost.

Compton scattering does not alter the CBR's spectrum as effectively as it mixes the radiation direction. This is because Compton scattering preserves the number of photons and because on the average it changes the energy of the photon by a fractional amount comparable to the ratio of the electron's kinetic energy to its rest mass, kT_e/m_ec^2. At the boundary ($z \approx 1000$) this factor is about 10^{-6}. Thus just before decoupling one scattering can change a photon's direction by a large angle; in contrast it would take about a million scatterings to change its energy by a large fraction. Compton scattering can effectively alter the CBR spectrum only at much higher temperatures and densities. The temperature and thus the electron kinetic energy scale as $(1 + z)$ and the number density of electrons scales as $(1 + z)^3$. At redshifts greater than a few times 10^4 there are sufficient scatterings and kinetic energy to thermalize the spectrum. However, since Compton scattering preserves the number of photons, the thermalized spectrum would be a Bose-Einstein distribution. One must go to even higher temperatures and densities to find processes that can effectively change the photon number. Radiative Compton scattering and bremsstrahlung (free-free emission) become important at redshifts greater than about 10^6. Both processes produce low-energy photons which must be Compton