Cosmic Background Radiation Research in 1988

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For Cosmic Background Radiation (CBR) research, 1988 was a very active year with tantalizing, although still controversial, results in both deviations from a purely blackbody spectrum and in a possible detection of anisotropy. It has now been forty years since the predictions of Alpher and Herman in 1948 that a cosmological background should exist, a remnant of a time when the universe was very hot. Predicted again in the early sixties by Dicke and Peebles at Princeton and by Doroshkevich and Novikov in the Soviet Union an experimental search was being undertaken by Wilkinson and Roll at Princeton when it was discovered by Penzias and Wilson at Bell Laboratories in 1965. Currently the Cosmic Background Radiation (CBR) is the subject of intense theoretical and experimental interest as it is one of our few accessible clues to the early universe and the processes that ultimately led to the current structure of clusters, voids, galaxies, and other objects we now observe. Radiation and matter would be tightly coupled in the early universe until a few hundred thousand years after the big bang when the temperature cooled enough so that the primordial plasma protons and electrons could combine to form neutral atoms. Since the seeds of galaxy formation should be present, at this time of decoupling, in the matter distribution as slight irregularities (inhomogeneities) in the matter density, these perturbations should also be present as slight temperature fluctuations in the background radiation. The theoretical predictions for the angular scale and magnitude of these anisotropies are severely hampered by our lack of understanding of how galaxies form at all. Do larger structures form and then fragment into galaxies? We do not understand this. Many current theories predict anisotropies to be important for galaxy and cluster formation in the 10 arc minute to 1 degree scale to be of the order of a few parts per million to a few tens of parts per million. Such perturbations though very small, recall that CBR temperature is only about 2.7 Kelvin, should be observable in the next few years if they exist. To make these extraordinarily sensitive measurements requires new technologies and extreme care in both detector development and antenna systems. One should maintain a healthy scepticism in both theory and experimental results as this field has historically been one of great difficulty.

In addition to the anisotropy, the spectrum (flux) of the radiation tells us a good deal about processes in the time after decoupling. Though ideally a blackbody (Planck) spectrum, numerous physical processes will modify this. Recombination photons emitted when the ionized electrons cascade to the ground state to form a neutral hydrogen atom, the Compton scattering of residual free electrons by the CBR photons particularly in the early stages of galaxy formation when there is sufficient nucleosynthesis in star formations to reionize significant amount of hydrogen, warm dust generated by a possible early generation of stars, and radiative decays of massive particles are a few of the processes that can distort an otherwise blackbody spectrum. Most of these processes tend to increase the flux in the high frequency side (Wien tail) of the flux vs. frequency distribution. This has also been an area of some experimental confusion in the past due to the subtle systematic errors that can come into the measurements. Fearless theorists, however, show no trepidation in explaining experimental results correct or not.

Recent Results

Two recent reports of deviation from a strictly isotropic blackbody radiation have been reported. Though both are still controversial and unconfirmed they have generated a flurry of theoretical interest.

Anisotropy

Davies et al. (1987) making measurements from a high altitude site in the Canary Islands at a wavelength of 3 cm (10 GHz) on an angular scale of 8° reports a detection of anisotropy at a level of $\Delta T/T = 4 \times 10^{-5}$. Interestingly this is at a similar level and angular scale to an older still controversial result of Melchiorri et al. (1982) of anisotropy at a 6° angular scale at high galactic latitudes using a balloon borne submillimeter ^4H_e bolometer. Davies et al. observed at fixed declimations and let the earth's rotation scan the instrument over the sky. The best data was taken at a declimation of +40°. Both measurements potentially suffer from significant contributions from galactic emission. For Davies et al. the primary problem is from synchrotron emission by high energy electrons in our galaxies magnetic field and by H II emission, regions of ionized hydrogen that emit by bremsstrahlung radiation. For Melchiorri et al. the primary galactic source of error is warm interstellar dust emission. Melchiorri et al. actually quotes their measurement as an upper limit due to possible contamination by dust emission.

In addition, Martin and Partridge have recently reported a possible detection of anisotropy on very small angular scales of 18 to 160 arc seconds at a level of $\Delta T/T = 2 \times 10^{-4}$. This measurement was done using the VLA (Very Large Array) at a wavelength of 6 cm (4860 MHz) on a region of the sky, which contained no rich clusters of galaxies as measured optically to 24th magnitude. This measurement also potentially suffers from emission by non-cosmological sources because of the long wavelength. Becasue of this problem the authors also quote an upper limit of $\Delta T/T = 4 \times 10^{-4}$. Further measurements at different frequencies will resolve this uncertainty.

Spectrum

Possible evidence of a distortion from a blackbody spectrum was recently reported by a collaboration of Japanese and U.S. scientists. In a rocket-borne experiment launched in Japan using a payload designed by groups at the University of Nagoya and the University of California at Berkeley a possible detection of excess emission at submillimeter wavelengths was observed. Since the observations were done at an altitude of about 300 km (sub-orbital flight) residual atmospheric emission is not important. The instrument used discrete bolometer/filter channels at about 1.2, 0.7, 0.5 mm to measure the CBR flux on the Wien side (short wavelength) of the spectrum. This has not been possible to do even from balloon altitudes because of atmospheric emission. Additional channels at even shorter wavelength measured interstellar dust emission. The results though still controversial indicate significant excess flux at 0.5 and 0.7 mm while the 1.2 mm channel agrees with longer wavelength measurements (Matsumoto et al., 1987). If these results are correct they will give us insight into processes that would inject energy into the CBR since decoupling. Possible sources include high Z dust from an early generation of stars and Compton (electron) scattering caused by the intense radiation that galaxy formation may have emitted which would reionize the hydrogen atoms in space. It is also possible that the effect is instrumental in nature. A second flight using a modified design with ^3H_e cooled detectors is planned for early 1989 to provide confirmation.

Future Experiments

1989 promises to be a bumper year for CBR research with a number of experiments to begin measurements. The NASA dedicated cosmology mission COBE (Cosmic Background Explorer) satellite is due to be launched in the summer. The satellite carries three complementary instrument packages that will make measurements from about 1μm to 1 cm in wavelength and will measure both the background radiation from 300 μm to 1 cm and search for evidence of primordial galaxy formation at the shorter wavelengths. The three instruments are the 1) DMR Differential Microwave Radiometer which will measure the angular structure (anisotropy) in the CBR on scales larger than about 10 degrees in wavelengths on 3.3, 5.7, and 9.1 mm with sensitivity at below a part in 10^5; 2) FIRAS

Far Infrared Absolute Spectrometer will measure the flux (spectrum) of the CBR very precisely from about 0.3 to 10 mm with resolution at the millikelvin level and 3) DIRBE Diffuse Infrared Background Experiment will measure diffuse emission from 1–300 μm. This is extremely important as it may give us the first clues of early galaxy formation. The COBE has been actively worked on for over a decade and promises to revolutionize our understanding of the early universe. In addition the Nagoya–Berkeley rocket experiment will fly to provide more information on the previously measured flux excess (COBE will also clarify this). Several groups are planning balloon-borne measurements of small scale anisotropy in a range of 0.1–10 degrees of angular scale. A number of groups are also pursuing ground based anisotropy measurements over a range of arc seconds to degrees with expected sensitivity of better than a part in 10^5. These measurements will be able to test many of the current theories of galaxy formation and will provide significant input to possible processes in the very early universe. Past measurements have caused significant changes in theories of the big bang model and were crucial in stimulating models such as the inflationary theories which provide a theoretical basis for the extreme smoothness observed in the background radiation. Several groups will be making anisotropy measurements from the south pole in late 1988 and early 1989 which promise to be the most sensitive yet at angular scales of about 1 degree. Millimeter and centimeter wavelength measurement of the spectrum of the CBR are also planned from both ground based and balloon-borne experiments. These will complement the COBE satellite which is most sensitive in the millimeter and submillimeter wavelengths.