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Cosmic Microwave Radiation Background; Its Primary Fluctuations

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Abstract: ***A cosmic ray proton of moderate energy striking a photon in the cosmic microwave background can only scatter the photon, a process whose rate is proportional to the square of the fine structure constant α≃ $^{1}/_{137}$. The discovery of the cosmic microwave background by Penzias and Wilson a lot of measurements have been performed on the Cosmic microwave background. The first measurements on the Cosmic Microwave Background confirmed that the spectrum would be a black body spectrum. And it was then found that the Cosmic Microwave Background is isotropic, i.e. the temperature of photons reaching the earth from different directions is the same. Later on, as measurements became more precise, it was found that this is not exactly true. The temperature of the photons is slightly different for different directions. It is necessary that the fluctuations be time-dependent, a photon falling into a time-independent potential well will lose the energy it gains when it climbs out of it. An important property of the Cosmic microwave back ground is that it preserves its black body Planck shape well after the thermalizing epoch is over, up to the present epoch. This is because the phase-space density of photons does not change there are no collisions or interactions that would change that density, n∝ $(e^{\frac{hv}{kT}} - 1)^{-1}$.***

Keywords: Isotropy, Spectrum, Scattering, Nucleosynthesis, Radiation

1. Introduction

The cosmic microwave background radiation was predicted in 1948 by George Gamow and Ralph Alpher. Moreover, they were able to estimate the temperature of this radiation to be 5 K.Two years later they re-estimated this temperature to be 28 K. These results were not widely discussed. Only in the early 1960's they were rediscovered by Yakov Zel'dovich. At the same time Robert Dicke predicted independently these same results. At some point in the history of our Universe a time was reached when it became energetically favorable for electrons and protons to be combined into neutral Hydrogen atoms. This is called the epoch of recombination because that's when P^+ and e^-combined, and also the epoch of decoupling because that's when the radiation decoupled from matter. Thomson scattering between electrons and photons ceased. The radiation was thermalized long before recombination; no significant non-thermal injection of energy took place since about z ~ 10^{10} -10^7. An important property of the Cosmic microwave background is that it preserves its black body Planck shape well after the thermalizing epoch is over, up to the present epoch. This is because the phase-space density of photons does not change there are no collisions or interactions that would change that density, n∝ $(e^{\frac{hv}{kT}} - 1)^{-1}$. Just after the big bang the universe was very hot and very dense. There were no neutral atoms or even nuclei. If a nucleus or atom was produced in would immediately be destroyed by a high energy photon. Matter and radiation were at thermal equilibrium at that time due to these rapid collisions between photons and free electrons, so called Compton scattering. Electrons were tightly coupled to protons via Coulomb scattering. As the universe expanded, it cooled down. At some the temperature of the universe dropped below the binding energies of typical nuclei. At that moment light elements started to form. Electrons were bound into neutral atoms, this process is called recombination. Because of recombination photons could no longer scatter of free electrons. Radiation decoupled from matter. This moment is therefore called decoupling. The surface where this took place, i.e. where the photons last scattered from the free electrons, is called last scattering surface. The photons started free streaming from that moment on, i.e. they were moving freely through the universe. Thus the photons which form the cosmic microwave background had their last interaction at the last scattering surface. By measuring the properties of these photons today, e.g. their temperature and their polarization, we can obtain information about the last scattering surface and thus about the early universe. Since the discovery of the cosmic microwave background by Penzias and Wilson a lot of measurements have been performed on the Cosmic Microwave background. The first measurements on the Cosmic Microwave Background confirmed that the spectrum would be a black body spectrum. And it was then found that the Cosmic Microwave Background is isotropic, i.e. the temperature of photons reaching the earth from different directions is the same. Later on, as measurements became more precise, it was found that this is not exactly true. The temperature of the photons is slightly different for different directions. Very important measurements on the Cosmic Microwave Background have been done by the COBE satellite, the Cosmic Back Ground Explorer, and by the WMAP, the Wilkinson Microwave Anisotropy Probe. The Cosmic Back- ground Explorer is a satellite developed by NASA in the seventies. It was put into sun-synchronous orbit in 1989. From then on in measured the temperature of the photons coming from all directions. It was announced in 1992 that small anisotropies were found in the temperature of the Cosmic Microwave Background, as measured by COBE. The WMAP was also developed by NASA, to succeed COBE. It was launched in 2001. The WMAP is able to do measurements with a much higher precision than the COBE, . The measurements done by the WMAP further confirm the existence of anisotropies in the temperature of the cosmic microwave background radiation. Both the COBE and the WMAP measure the temperature of all incoming photons. These incoming photons will not only be photons from the Cosmic

Microwave Background, but also from a lot of other sources such as our galaxy. To keep this to a minimum the WMAP is put in an orbit behind the earth, such that it will not receive photons coming from the Sun. To obtain information about the Cosmic Microwave Background a distinction has to be made between photons from the Cosmic Microwave Background and other photons. Measurements of these other photons have to subtracted so that we are only left with CMB measurements. This process is called foreground subtraction and it is done in several ways, . Firstly, a lot of measured photons are emitted at known source, such as stars and planets we know. Since the location and the properties of these sources are known, they can be removed from the data. Secondly, it is used that the spectrum of the photons making up the Cosmic Microwave Background is a perfect black body spectrum. Photons coming from other sources have a different spectrum and in this way one can distinguish between the different photons. In order to do this observations are made at multiple frequencies.. The final set of data consists of the measured temperature in all different directions. From this set information can be obtained about anisotropies of the Cosmic Microwave Background. Thus what is measured is the temperature of photons of the cosmic microwave back- ground coming from different directions. The temperature of the cosmic background is the mean value of all these temperatures. T = 2.725±0.001K. The temperature differences are then expressed as the difference between the measured temperature and the average temperature. The fluctuations are very small, of the order μK.

2. Literature Survey

It was George Gamow and his collaborators who first recognized in the late 1940s that the universe should now be filled with black-body radiation.

The first plausible estimate of the present temperature of this made in 1950 by Ralph Alpher and Robert Herman.2 On the basis of considerations of cosmological nucleosynthesis, they found a present temperature of 5 K. This work was largely forgotten in subsequent decades, until in 1965 a group at Princeton started to search for a cosmic radiation background left over from the early universe. They had only a rough idea of the temperature to be expected, based on a nucleosynthesis calculation of P. J. E. Peebles, which suggested a value of 10 K.3 Before they could complete their experiment the radiation was discovered in a study of noise backgrounds in a radio telescope by Arno Penzias and Robert Wilson, 4 who published their work along with a companion article5 by the Princeton group explaining its possible cosmological significance.6 Originally Penzias and Wilson could only report that the antenna temperature at a wavelength 7.5 cm was 3.5±1.0 K, meaning that the intensity of the radiation *at this one wavelength* agreed with this temperature. This of course did not show that they were observing black-body radiation. Then Roll and Wilkinson measured the radiation intensity at a wavelength of 3.2 cm, finding an antenna temperature of 3.0 ± 0.5 K, in agreement with what would be expected for black-body radiation at the temperature measured by Penzias and Wilson. In the following few years a large number of measurements were made by other radio astronomers at other wavelengths. These measurements also gave antenna temperatures at the wavelengths being studied around 3 K, with uncertainties that gradually improved to of order 0.2 K. But this also did not establish the black-body nature of the radiation, because these measurements were all at wavelengths greater than about 0.3 cm, where the black-body energy distribution *hνnT (ν)* with $T \approx 3$ K has its maximum, cosmic microwave background**,** also called cosmic background radiation, electromagnetic radiation filling the universe that is a residual effect of the big bang 13.8 billion years ago. Because the expanding universe has cooled since this primordial explosion, the background radiation is in the microwave region of the electromagnetic spectrum. Beginning in 1948, the American cosmologist George Gamow and his co-workers, Ralph Alpher and Robert Herman, investigated the idea that the chemical elements might have been synthesized by thermonuclear reactions that took place in a primeval fireball. According to their calculations, the high temperature associated with the early universe would have given rise to a thermal radiation field, which has a unique distribution of intensity with wavelength (known as Planck's radiation law), that is a function only of the temperature. As the universe expanded, the temperature would have dropped, each photon being redshifted by the cosmological expansion to longer wavelength, as the American physicist Richard C. Tolman had already shown in 1934. By the present epoch the radiation temperature would have dropped to very low values, about 5° above absolute zero(0 kelvin [K], or −273 °C [−460 °F]) according to the estimates of Alpher and Herman. Interest in these calculations waned among most astronomers when it became apparent that the lion's share of the synthesis of elements heavier than helium must have occurred inside stars rather than in a hot big bang. In the early 1960s physicists at Princeton University, N.J., as well as in the Soviet Union, took up the problem again and began to build a microwave receiver that might detect, in the words of the Belgian cleric and cosmologist Georges Lemaître, "the vanished brilliance of the origin of the worlds." The actual discovery of the relict radiation from the primeval fireball, however, occurred by accident. In experiments conducted in connection with the first Telstar communication satellite, two scientists, Arno Penzias and Robert Wilson, of the Bell Telephone Laboratories, Holmdel, N.J., measured excess radio noise that seemed to come from the sky in a completely isotropic fashion (that is, the radio noise was the same in every direction). When they consulted Bernard Burke of the Massachusetts Institute of Technology, Cambridge, about the problem, Burke realized that Penzias and Wilson had most likely found the cosmic background radiation that Robert H. Dicke, P.J.E. Peebles, and their colleagues at Princeton were planning to search for. Put in touch with one another, the two groups published simultaneously in 1965 papers detailing the prediction and discovery of a universal thermal radiation field with a temperature of about 3 K.

Precise measurements made by the Cosmic Background Explorer (COBE) satellite launched in 1989 determined the spectrum to be exactly characteristic of a blackbody at 2.735 K. The velocity of the satellite about Earth, Earth about the Sun, the Sun about the Galaxy, and the Galaxy through the universe actually makes the temperature seem slightly hotter (by about one part in 1, 000) in the direction of motion rather than away from it. The magnitude of this effect—the so-called dipole anisotropy—allows astronomers to determine that the Local Group (the group of galaxies containing the Milky Way Galaxy) is moving at a speed of about 600 km per second (km/s; 400 miles per second [miles/s]) in a direction that is 45° from the direction of the Virgo cluster of galaxies. Such motion is not measured relative to the galaxies themselves (the Virgo galaxies have an average velocity of recession of about 1, 000 km/s [600 miles/s] with respect to the Milky Way system) but relative to a local frame of reference in which the cosmic microwave background radiation would appear as a perfect Planck spectrum with a single radiation temperature. The COBE satellite carried instrumentation aboard that allowed it to measure small fluctuations in intensity of the background radiation that would be the beginning of structure (i.e., galaxies and clusters of galaxies) in the universe. The satellite transmitted an intensity pattern in angular projection at a wavelength of 0.57 cm after the subtraction of a uniform background at a temperature of 2.735 K. Bright regions at the upper right and dark regions at the lower left showed the dipole asymmetry. A bright strip across the middle represented excess thermal emission from the Milky Way. To obtain the fluctuations on smaller angular scales, it was necessary to subtract both the dipole and the galactic contributions. An image was obtained showing the final product after the subtraction. Patches of light and dark represented temperature fluctuations that amount to about one part in 100, 000—not much higher than the accuracy of the measurements. Nevertheless, the statistics of the distribution of angular fluctuations appeared different from random noise, and so the members of the COBE investigative team found the first evidence for the departure from exact isotropy that theoretical cosmologists long predicted must be there in order for galaxies and clusters of galaxies to condense from an otherwise structure-less universe. These fluctuations correspond to distance scales on the order of 10^9 light-years across (still larger than the largest material structures seen in the universe, such as the enormous grouping of galaxies dubbed the "Great Wall"). The Wilkinson Microwave Anisotropy Probe (WMAP) was launched in 1995 to observe the fluctuations seen by COBE in greater detail and with more sensitivity. The conditions at the beginning of the universe left their imprint on the size of the fluctuations. WMAP's accurate measurements showed that the early universe was 63 percent dark matter, 15 percent photons, 12 percent atoms, and 10 percent neutrinos. Today the universe is 72.6 percent dark energy, 22.8 percent dark matter, and 4.6 percent atoms. Although neutrinos are now a negligible component of the universe, they form their own cosmic background, which was discovered by WMAP. WMAP also showed that the first stars in the universe formed half a billion years after the big bang.

3. Problem Definition

The black-body spectrum of the cosmic microwave radiation background began to be established by balloon-borne and rocket-borne observations above the earth's atmosphere at wavelengths below 0.3 cm. For some years there were indications of an excess over the black-body formula at these short wavelengths. It was clearly necessary to do these observations from space, but this is difficult; to measure the absolute value of the microwave radiation intensity it is necessary to compare the radiation received from space with that emitted by a "cold load" of liquid helium, which rapidly evaporates. Finally, the Planck spectrum of the microwave background was settled in the 1990s by observations with the FIRAS radiometer carried by the Cosmic Background Explorer Satellite (COBE), launched in November 1989. When a slide showing the agreement of the observed spectrum with the Planck black-body spectrum was shown by J. C. Mather at a meeting of the American Astronomical Society in January 1990, it received a standing ovation. It was found that the background radiation has a nearly exact black-body spectrum in the wavelength range from 0.5 cm to 0.05 cm. After six years of further analysis, the temperature was given as 2.725 ± 0.002 K (95% confidence). Other observations at wavelength between 3 cm and 75 cm and at 0.03 cm are all consistent with a Planck distribution at this temperature. And also Cosmic microwave background that arise from effects in the recent universe: the motion of the earth relative to the cosmic microwave background, and the scattering of light by intergalactic electrons in clusters of galaxies along the line of sight. Now we turn to general anisotropies, including the highly revealing *primary* anisotropies that have their origin in the early universe.

4. Methodology

Before decoupling radiation and matter were in thermal equilibrium. The number density of photons in equilibrium with matter at temperature T at photon frequency between v and v+dv is given by

$$n_T(v)d_v = \frac{8\pi v^2 d_v}{\exp\left({}^{h_v}/_{k_b T}\right) - 1} \text{ ---- } eq^n \qquad \text{(a)}$$

where h is the original Planck's constant and kB is the Boltzmann constant is a so called black body spectrum. After decoupling photons were no longer in thermal equilibrium with electrons and they started free streaming. But the spectrum of the photons has kept the same form. That the from of the spectrum has stayed the same is most easily seen by assuming that there was one time where radiation went from being in thermal equilibrium with matter to a free expansion. This time is denoted by T_l where the subscript L stands for last scattering. A freely moving photon at some later time t with frequency v would have had at time t_L a frequency ${}^{v_a(t)}/_{a(t_L)}$, where

a(t) is the expansion rate at time t. So the number density of photons with a frequency between v and $v + d_v$ at time t would be

$$n(v,t)d_v = \left(\frac{a(t_L)}{a(t)}\right)^3 nT(t_L)\left(\frac{va(t)}{a(t_L)}\right) d\left(\frac{va\ (t)}{a(t_L)}\right) \text{ -----} eq^n \qquad \text{(b)}$$

With the factor $\left(\frac{a(t_L)}{a(t)}\right)^3$ arising from the dilution of photon due to the cosmic expantion.Using eq^n (a) in eq^n (b)

We se the Redshift factor $\frac{a(t)}{a(t_L)}$ all cancel in the exponential, so that the number density at time t is given by

$$n(v, t)d_v = \frac{8\pi v^2 d_v}{\exp\left(\frac{h_v}{k_B T(t)}\right)-1} = n_{T(t)}(v)d_v \text{ ----------} eq^n \qquad (c)$$

where

$$T(t) = \frac{T(t_L)a(t_L)}{a(t)} \text{ ---------} eq^n \qquad (d)$$

Thus the photon density has been given by the black-body form even form even after the photons went out of equilibrium with Matter, but with a redshifted temperature as in equation (d). This conclusion is obviously unchanged if the transition from opacity to transparency occupied a finite time interval, as long as Interactions of photons with matter during this interval are limited to elastic scattering processes in which photon frequency are not changed.

5. Discussion

The cosmic microwave background radiation was portend by George Gamow and Ralph Alpher. Temperature is measured by them was 5k.Two year later they re-estimate this temperature to be 28k.This shows that it increased when time passed.

At the same time Robert Dicke predicted independently these same results. At some point in the history of our Universe a time was reached when it became energetically favorable for electrons and protons to be combined into neutral Hydrogen atom. This is the era of recombination. When P^+ and e^- combined and also the epoch of decoupling because that's when the radiation decoupled from matter. Thomson scattering between electrons and photons ceased. Before recombination hypothetical observers weren't able to see anything around them because the mean free path for photons was very short. After recombination photons could fly free, mostly unimpeded by scatterings with electrons or atoms. If we were an observer at that epoch, it would be similar to having the fog clear up around us. Wilkinson and Roll use it for radio astronomy and satellite experiment communication. Their radiometer has excess 3.5k antenna which the could not account for less energetic than the radiation come from Milky way and more it was Isotropic.

6. Conclusion

There is an effect of the cosmic microwave background that has long been expected but has been difficult to observe. A cosmic ray proton of moderate energy striking a photon in the cosmic microwave background can only scatter the photon, a process whose rate is proportional to the square of the fine structure constant $\alpha \simeq {}^1/_{137}$. However, if the proton has sufficiently high energy then it is also possible for the photon to be converted into a π meson in the reactions $\gamma + p \rightarrow \pi^0 + p$ or $\gamma + p \rightarrow \pi^+ + n$, processes whose rate is proportional to α, not α^2. Assuming that high energy cosmic rays come to us from outside our galaxy, we therefore expect a dip in the spectrum of cosmic ray protons at an energy where the cross section for these processes becomes appreciable. The primary anisotropies in the cosmic microwave background arise from several sources, Intrinsic temperature fluctuations in the electron–nucleon–photon plasma at the time of last scattering, at a redshift of about 1, 090. The Doppler effect due to velocity fluctuations in the plasma at last scattering. The gravitational redshift or blueshift due to fluctuations in the gravitational potential at last scattering. Gravitational redshifts or blueshifts due to time-dependent fluctuations in the gravitational potential between the time of last scattering and the present.

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