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The Cosmic Microwave Background: A Strange Characteristic

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ABSTRACT

The ratio of the self-gravitational energy density of the scattering particles in the universe to the energy density of the scattered photons in the Cosmic Microwave Background (CMB) is the same in any volume of space. These two energy densities are equal at a radiation temperature on the order of the present CMB temperature.

Keywords: Cosmic Microwave Background-Observable Universe-Gravitation

1. INTRODUCTION

One can hardly overestimate the importance of the Cosmic Microwave Background (CMB) for the standard cosmological model. What started as an inference of an “effective temperature of space” (McKellar, 1941) based on the “absorption lines of the cyanogen radical” in the interstellar clouds (Adams, 1941), surfaced 7 years latter as a prerequisite for the observed “cosmic abundances of the light elements” (Gamow, 1948; Alpher and Herman, 1948), fell into oblivion for almost a quarter of a century and, finally, was brought to light as “a measurement of excess antenna temperature” (Penzias and Wilson, 1965), proved to be one of the best pieces of evidence for the big bang model of the universe. The existence of the CMB not only shows that the universe was once very hot and dense, but allows us to learn more about the origin of galaxies and large scale structures of the universe and to estimate the values of the basic parameters of the standard cosmological model. It is therefore very important to know as much as possible about the properties and characteristics of this important source of information. With this objective in mind we present here a strange characteristic of the CMB, which can be a coincidence or can be the result of a yet unknown property.

2. A STRANGE CHARACTERISTIC

Let us consider an arbitrary volume of space of radius r containing a fully ionized, homogenous mixture of matter and thermal radiation. If the photon number density n_γ is much larger than the number density n_e of scattering particles (as is the case with the CMB) all particles are practically immersed in a bath of thermal radiation. The scattering particles (mostly free electrons) in the radiation bath scatter the incoming photons and act as sources of radiation of luminosity L_e. The collision rate of a free electron with a photon of frequency ω in the range $d\omega$ is $df_e = c\sigma_T n_\gamma(\omega)d\omega$, where c is the speed of light and σ_τ is the Thomson cross section. Due to the electric field in the electromagnetic wave the electron accelerates and emits radiation of the same frequency. The energy radiated in unit time in the above range is $dL_e = \hbar\omega df_e$, where, $h = 2\pi\hbar$ is the Planck constant. Using the Planck distribution Equation (1):

$$n_\gamma(\omega)\,d\omega = \frac{1}{\pi^2 c^3}\frac{\omega^3 d\omega}{e^{\hbar\omega/kT} - 1} \tag{1}$$

where, k is the Boltzmann constant, one obtains (Dinculescu, 2007) Equation (2):

$$L_e = c\sigma_T \int_0^\infty \frac{\hbar}{\pi^2 c^3}\frac{\omega^3 d\omega}{e^{\hbar\omega/kT} - 1} = c\sigma_T u_\gamma \tag{2}$$

(Here $u_\gamma = a T_\gamma^4$ is the radiation density, T_γ is the radiation temperature and Equation (3):

$$a = \frac{\pi^2}{15} \frac{\left(kT_\gamma\right)^4}{\left(\hbar c\right)^3} \tag{3}$$

is the radiation density constant). With the scattered luminosity per unit volume $L_{ne} = n_e \sigma_T c u_\gamma$ and the escape time of a photon from the volume $t_{esc} = \sigma_T n_e r^2/c$, the energy density of the scattered radiation inside our volume of space is $u_* = L_{ne} t_{esc} = u_\gamma \tau^2$. If one ignores those particles that practically do not play any role in the process (the protons, the neutrons and the unscattered photons), one is left out with a mixture of free electrons and scattered photons that oppose gravitational attraction between them. It is therefore natural to compare the energy density $u_* = u_\gamma \tau^2$ of the scattered photons with the self-gravitational energy density Equation (4):

$$u_{eG} = \frac{3}{5}\frac{3}{4\pi}\frac{GM_e^2}{r^4} \tag{4}$$

of the scattering particles. With Equation (5):

$$M_e = \frac{4\pi}{3} n_e m_e r^3 \tag{5}$$

where, m_e is the mass of the electron, the two energy densities are equal when Equation (6):

$$aT_\gamma^4 = \frac{4\pi}{5}\frac{Gm_e^2}{\sigma_T^2} \tag{6}$$

This corresponds to a radiation temperature practically equal to the present CMB temperature (Fixen and Mather, 2002). The apparent equality between the self-gravitational energy density of the free electrons and the energy density of the scattered radiation in a volume of space at the present epoch adds to the list of "numerical coincidences" that seems to suggest we are living in a special epoch (Dinculescu, 2009), a conclusion that although contradicts the Copernican Principle seems to find some justification in the Anthropic Principle (Barrow and Tipler, 1986).

It is interesting to note that the ratio of the self-gravitational energy density of matter to the energy density of the scattered CMB Equation (7):

$$\frac{u_{bG}}{u_*} = \frac{4\pi}{5}\frac{G m_p^2}{u_\gamma \sigma_T^2 (1 - Y_p/2)} = \frac{m_p^2}{m_e^2 (1 - Y_p/2)} \tag{7}$$

(where, m_p is the mass of the proton and Y_p is the helium mass fraction) is the same in any volume of space, a not very often encounter property when dealing with gravitation, where the sum of the energies of the constituent sub-systems is not equal to the total energy of the system.

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