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Photon Creation in the Universe and Primordial Nucleosynthesis

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Abstract. In hot big bang cosmologies, the irreversible process of continous photon creation may phenomenologically be described through a thermodynamic approach. In these models, the radiation temperature law depends on a phenomenological parameter β which is closely related to the photon creation rate. It is shown that a stringent constraint on the value of this parameter is imposed from primordial nucleosynthesis.

1. Cosmology with photon creation

The increasing difficulties of the standard CDM cosmology are now compelling the investigation of alternative big-bang mo- dels. One of the main observational motivations is the conflict between the expanding age of the universe, as inferred from recent measurements of the Hubble parameter (Friedmann 2000) and the age of the oldest stars in globular clusters (Pont et al. 1998).

It is also widely believed that matter and radiation need to be created in order to overcome some conceptual problems of the standard hot big bang model. In this concern, a thermodynamic description for gravitational creation of matter and radiation has been proposed in the literature (Prigogine et al. 1989; Calvão et al. 1992). The crucial ingredient of this formulation is the explicit use of a balance equation for the number density of the created particles in addition to Einstein field equations. In this framework, the thermodynamic second law leads naturally to a reinterpretation of the energy momentum tensor corresponding to an additional stress term (creation pressure), which in turn depends on the photon creation rate, and alters considerably the observational predictions of the CDM model (Lima and Alcaniz 1999; Alcaniz and Lima 1999).

In this context, by addopting a photon creation scenario recently discussed (Lima and Abramo 1999; Wichoski and Lima 1999), an upper limit to the creation parameter is derived from primordial nucleosynthesis constraints.

The Einstein field equations for a fluid endowed with "adiabatic" photon creation and the balance equation for the particle number density are (Calvão et al. 1992)

$$8\pi G\rho = 3\frac{\dot{R}^2}{R^2} \quad , \tag{1}$$

$$8\pi G(p + p_c) = -2\frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} \quad , \tag{2}$$

Table 1. Limits to β

η	^{4}He Abundance	β
10^{-12}	≤ 0.25	≤ 0.15
10^{-11}	≤ 0.25	≤ 0.12
10^{-10}	≤ 0.25	≤ 0.06

$$\frac{\dot{n}}{n} + 3\frac{\dot{R}}{R} = \frac{\psi}{n} \quad , \tag{3}$$

where an overdot means time derivative and ρ, p, n and ψ are the energy density, pressure, particle number density and photon creation rate, respectively. The creation pressure p_c depends on the photon creation rate, and for "adiabatic" photon creation takes the form $p_c = -\frac{\rho+p}{3nH}\psi$ (Calvão et al. 1992).

Let us now assume a physically reasonable expression to the photon creation rate ψ. In this work we confine our attention to the simplest phenomenological expression $\psi = 3\beta nH$ (Lima et al. 1996), where β is smaller than unity, and given by some particular microscopic model for gravitational creation. This parameter must be a function of the cosmic era, however, in what follows we assume only photon creation (β constant).

2. Limits to β

Modifying the Wagoner-Kawano code (Kawano 1992), we have put limits on the photon creation rate β. In virtue of the photon creation process, the baryon-to-photon ratio is a function of time, which is now expressed as

$$\eta = \eta_{today} \left(\frac{T_9}{T_o \times 10^{-9}} \right)^{\frac{3\beta}{(1-\beta)}} . \tag{4}$$

The ^{4}He abundance as a function of the baryon-to-photon ratio for some selected values of β parameter is shown in Fig. 1. The limits derived for the β parameter have been obtained assuming a fixed maximum abundance for ^{4}He (≤ 0.25), $N_\nu = 3$, $\tau_n = 887 \pm 2$, and several lower bounds for η. The limits on the β parameter obtained from ^{4}He abundance are summarized in Table 1.

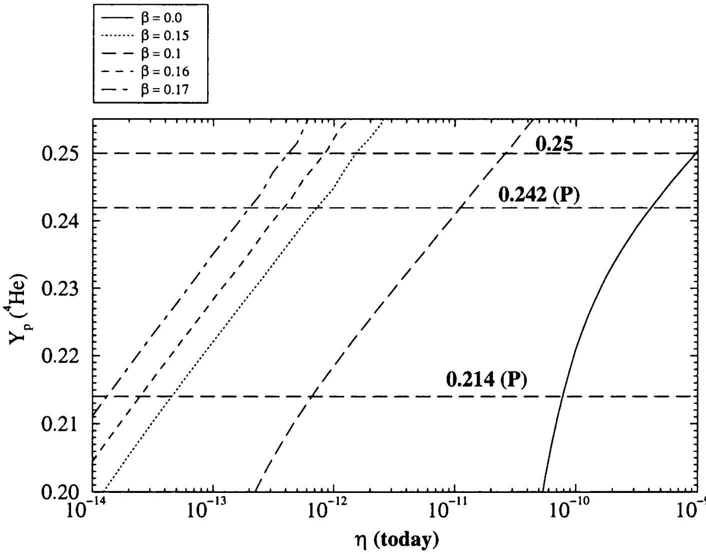

Figure 1. The ^{4}He abundance as a function of the baryon-to-photon ratio for some selected values of β parameter. Dashed lines labelled as 0.214 (P) and 0.242 (P) stand for the ^{4}He abundance (95% cl) obtained by Pagel et al (1992).

Acknowledgments

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