The Light Elements and Their Evolution
IAU Symposium, Vol. 198, 2000
L. da Silva, M. Spite, J. R. de Medeiros, eds.

Cosmological gravitons back reaction and the primordial nucleosynthesis

M. R. G. Maia[1], J. C. Carvalho[1], J. S. Alcaniz[1] and J. M. F. Maia[1,2]

[1]*Departamento de Física-UFRN, CP 1641, 59072-970 Natal, RN-Brasil*
[2]*Instituto de Física-USP, CP 66318, 05389-970 São Paulo, SP-Brasil*

Abstract. The back reaction of effective gravitons created during noninflationary epochs due to the inequivalence of vacuum states at different eras is examined in the context of primordial nucleosynthesis. Our final purpose is to obtain limits on the model employed to study such a process.

The inequivalence of vacuum states at different eras of the history of the universe determines the production of gravitational waves in scales larger than the Hubble lengh. During noninflationary periods of expansion, these very long tensor perturbations (VLTP's) enter the Hubble radius, thus becoming effective gravitational waves (EGW's) (Allen 1988). Such an effect adds new contributions to the gravitons energy density ρ_g within the horizon, the modes energetically meningful, and can be described by using a macroscopic approach to matter creation (see de Garcia Maia et al., 1997 an references therein). This is done by introducing a creation pressure term in the balance equation for ρ_g and the EWG's back reaction leads to the following dynamical equation for the scale factor $a(t)$ during the radiation era (for the flat case):

$$\frac{\ddot{a}}{a} + \frac{3\gamma_r - 2}{2}\frac{\dot{a}^2}{a^2} = 4\pi G\left(\gamma_r \rho_g + \frac{\dot{\rho}_g}{3H}\right), \qquad (1)$$

where H is the Hubble parameter, γ_r is the barotropic parameter related to the dominant component of the era denote by the subscript r and the whole R.H.S. is due to the effective gravitons creation process. It can be shown (de Garcia Maia et al. 1997) that given γ_{r-1}, γ_r and $H(t_r)$, the explicit expression for ρ_g is univocally determined in terms of $a(t)$ and $\dot{a}(t)$, so that $a(t)$ can be determined.

Here, we will consider that a transition occurred between a phase denoted by $r = 0$, for example an inflationary period, to the radiation era ($r = 1$). In such a case,

$$\rho_g(t) = \frac{1}{\pi^2}\left[\frac{(3\gamma_0 - 2)H_1}{2}\right]^4 \left[\frac{a_1}{a(t)}\right]^4 I(t), \qquad (2)$$

where $I(t)$ accounts for the graviton creation and is given by (Carvalho et al. 2000)

$$I(t) = \frac{(2m_0+1)^2\Gamma^2(-m_0)}{\pi(2m_0+3)2^{2m_0+5}}\left[1 - \left(\frac{4\pi}{a_1 H_1(3\gamma_0 - 2)}\dot{a}(t)\right)^{2m_0+3}\right], \qquad (3)$$

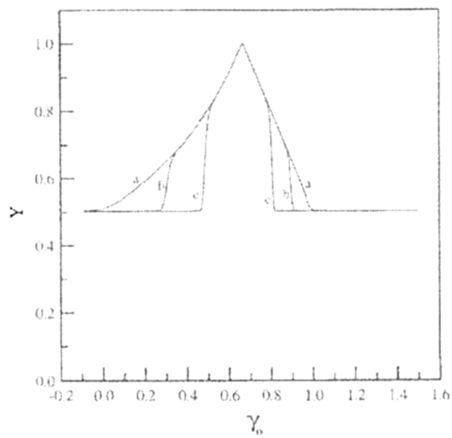

Figure 1. The asymptotic value of the slope $Y = [d\log a(t)/a_1][d\log t]$ as a function of the barotropic parameter γ_o. Curves (a), (b), and (c) correspond to $(H_1/m_{\text{planck}}) = 1$, $(H_1/m_{\text{planck}}) = 10^{-5}$, $(H_1/m_{\text{planck}}) = 10^{-10}$, repectively. As can be seen, as γ_o gets close to 2/3, the slope Y changes drastically from the standard value 1/2 to peak at the value 1 for $\gamma_o = 2/3$.

with $m_r \equiv 2/(3\gamma_r - 2) - 1/2$. For details on obtaining the above equations, see de Garcia Maia et al. 1997.

We should mention that the production of VLTP's is a natural outcome of quantum mechanics and general relativity in the cosmological context. This phenomenon may predict observational effects, depending on the values of free parameters of the model (de Garcia Maia et al. 1999). Here, we are interested in constraining these parameters from a primordial nucleosynthesis analysis.

Since only effective gravitons are produced, and they are not coupled to the other particles at almost all times of the thermal history of the universe, the radiation expands adiabatically, as in the standard picture. The main modification on primordial nucleosynthesis comes from the time-temperature relation, due to the back reaction effect on the expansion rate (Carvalho et al. 2000):

$$t = 2(10.4)^2 \int_T^\infty \frac{dT}{T^3\sqrt{1+\alpha I(T)}}, \tag{4}$$

where $\alpha = 4(10.4)^4 \frac{8GH_1}{3\pi}(\frac{3\gamma_0 - 2}{2T_1})^4$. We are presently implementing the numerical code to solve the above equation as well as making the necessary modifications on Kawano's code (Kawano 1992) in order to determine the bounds on the parameter γ_0 from nucleosynthesis. Because the dynamics of the Universe is not very sensitive to the value of H_1 (de Garcia Maia et al. 1997), we expect that for $\gamma_0 \sim 2/3$ the standard results will be considerably affected (see Fig. 1). In

https://doi.org/10.1017/S0074180900166446 Published online by Cambridge University Press

particular, the present estimates of the ^{4}He abundance could impose constraints on the possible values of γ_0 (Carvalho et al. 2000).

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