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The Recombination in a FRW Universe with a Variable Cosmological Term

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Abstract. The effects of a time-dependent Λ term in the recombination epoch are analysed taking into account the main physical processes occurring in the primordial plasma. For a vacuum decaying into photons, we show that the recombination begins when the Universe was smaller and denser, leading to a greater recombination rate. These results may have several implications to the large scale structure. In particular, the earlier recombination means that more time is available to the evolution of density perturbations.

1. The Model

We consider an adiabatic model with a Λ–term decaying into photons (Lima 1996 and Lima and Trodden 1996), given by $c^2\Lambda_v(t) = 8\pi G\beta\rho_T$, where ρ_T is the total energy density (radiation, matter and vacuum). The parameter $\beta < 0.16$ is constrained from nucleosynthesis studies (Maia et al. 2000). In this model the temperature law scales as $T_\gamma \propto a^{1-\beta}$, where a is the scale factor. For FRW models with a Λ-term, the age of the Universe reads

$$H_0 t_0 = \int_0^1 \left(\frac{(1-\beta)x^{(1-3\beta)}}{\Omega_{m0} + (1-\beta-\Omega_{m0}-\lambda_0)x^{(1-3\beta)} + \lambda_0 x^{3(1-\beta)}} \right)^{1/2} dx, \qquad (1)$$

where $H_0 = 100\ h\text{Mpc}^{-1}\text{km s}^{-1}$ is the Hubble constant, $\lambda_0 = \Lambda_c/3H_0^2$ is the cosmological constant and $\Omega_{m0} = (8\pi G/3H_0^2)\rho_{m0}$ is the matter density parameter. The index "0" denotes the present day values. Assuming that the Universe is a mixture of protons, electrons and hydrogen, we consider a variety of physical processes envolving matter and radiation during and after recombination: photon drag, ionization due to radiation and electronic collisions, recombination cooling and Compton heating–cooling (Opher et al. 1998).

The results have been obtained using a hydrodynamical code (including the above processes), and are summarized in the table below. All models are parametrized by Ω_{m0}, h, β, and λ_0. This table yields the temperature of the radiation, $T_{\gamma rec}$ and the redshift, z_{rec}, at the recombination epoch, which is assumed to occur when 50% of the electrons have been captured. The last column of this table yields the age of the Universe as given by (1).

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Model	Ω_{m0}	h	β	λ_0	$T_{\gamma rec}(K)$	z_{rec}	$Age(Gyr)$
A1	0,024	0,73	0,1	0,0	3900	3201	13,1
A2	"	"	0,05	0,0	3740	2003	13,0
A3	"	"	0,0	0,876	3540	1296	20,3
A4	"	"	0,1	0,876	3920	3220	25,1
A5	"	"	0,0	0,0	3540	1296	12,9
B1	0,05	0,5	0,1	0,0	3900	3201	18,8
B2	"	"	0,05	0,0	3740	2003	18,6
B3	"	"	0,0	0,85	3540	1296	26,7
B4	"	"	0,1	0,85	3920	3220	31,7
B5	"	"	0,0	0,0	3540	1296	18,3
C1	0,1	0,73	0,1	0,0	4070	3357	12,5
C2	"	"	0,05	0,0	3900	2093	12,3
C3	"	"	0,0	0,8	3720	1362	16,1
C4	"	"	0,1	0,8	4070	3357	18,6
C5	"	"	0,0	0,0	3720	1362	12,0
D1	0,1	0,5	0,1	0,0	3990	3283	18,3
D2	"	"	0,05	0,0	3820	2048	17,9
D3	"	"	0,0	0,8	3620	1325	23,5
D4	"	"	0,1	0,8	3990	3283	27,1
D5	"	"	0,0	0,0	3620	1325	17,6

2. CONCLUSIONS

For models with cosmological constant (or standard CDM), same results already established are also diplayed: The recombination begins in a higher redshift if the Universe is denser. The Universe is older if the cosmological constant increases (for the same h). For models with a decaying vacuum into photons the main results are:
1) $\beta \neq 0$ always increases the age of the Universe.
2) The recombination temperature ($T_{\gamma rec}$) is greater and the same happens with the redshift (z_{rec}).
3) The β parameter has also a deep influence on the late time evolution of fluctuations. In particular, comparing several models at equal redshift, the Jeans mass is smaller if the β parameter increases.

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