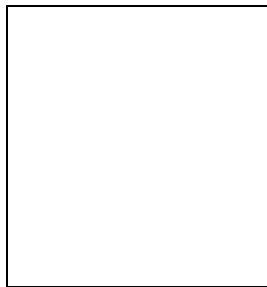


# CORRELATED MIXTURES OF ADIABATIC AND ISOCURVATURE COSMOLOGICAL PERTURBATIONS

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The Cosmic Microwave Background (CMB) anisotropies measurements can provide many clues about the Universe. Although the common belief is that they will allow a very precise measurement of the cosmological parameters (that is, the current state of the Universe), they will alternatively give interesting informations about the state of the initial perturbations (that is, the state of the Universe at the end of inflation). In this paper, we study the observational consequences on the CMB anisotropies of some wide set of initial conditions, with a correlated mixture of adiabatic and isocurvature perturbations.

## 1 Introduction

The CMB anisotropies can indirectly measure the cosmological parameters by looking at the evolution of the cosmological perturbations between the end of inflation and the recombination epoch. In order to do so, one must implicitly assume a simple form for the initial perturbations. Usually, one considers only adiabatic fluctuations, with a power law spectrum.

Adiabatic fluctuations arise in the context of the simplest inflationary scenario. However, as soon as one has a multiple inflation scenario, isocurvature fluctuations can be generated, the amplitude of which, as well as their correlation with the adiabatic part, depend on the parameters of the model. In many of the models already studied<sup>1</sup>, the isocurvature and the adiabatic parts of the fluctuations are uncorrelated, but it is possible to have a correlated mixture of such perturbations, as was already stressed by one of us<sup>2</sup> in the study of a specific inflation model with two massive non interacting scalar fields.

In this communication, we study this issue in a phenomenological way, and look at the observable consequences of a correlated mixture of adiabatic and isocurvature cosmological perturbations. These perturbations happen to have a richer structure than the more usual uncorrelated adiabatic and isocurvature ones.

## 2 Definitions and notations

When considering a mixture of several fluids, one can define an entropy perturbation  $S_{A,B}$  for any pair of components  $A$  and  $B$ . It is non zero as soon as the different particle number density contrasts  $\delta n_X/n_X$  ( $X = A, B$ ), are not equal. It can also be written in terms of energy density contrasts  $\delta_X$  :

$$S_{A,B} \equiv \frac{\delta n_A}{n_A} - \frac{\delta n_B}{n_B} = \frac{\delta_A}{1 + \omega_A} - \frac{\delta_B}{1 + \omega_B}, \quad (1)$$

where  $\omega_X \equiv p_X/\rho_X$  is the equation of state parameter for the species  $X$ . (Note that this definition is gauge-invariant.) Adiabatic initial conditions are defined such that all the entropy perturbations are zero. In cosmology, the perturbations are actually considered as random fields, usually assumed to be Gaussian, and described by their power spectra. When one has to deal with several random fields, one must also impose the form of the cross-correlation between them. In what follows, we will consider only *totally correlated* adiabatic and isocurvature perturbations, where all the random fields are described in terms of a single random variable. We further assume that only one species deviates from adiabaticity. In this case, one simply has to define which species deviates from adiabaticity, say  $X$  (i.e.  $S_{A,B} = 0$  when  $A, B \neq X$ ), and the relative initial amplitude between the entropy perturbation  $S_{X,Y}$  and the Bardeen potential  $\Phi$  (where  $Y$  is another species which does not deviate from adiabaticity) :

$$S_{X,Y} \equiv \lambda \Phi. \quad (2)$$

We will then talk about “ $X$  hybrid perturbation”.

## 3 An analytical estimate

Adiabatic scale invariant initial conditions make two predictions concerning the CMB anisotropies. First, they predict a flat (Sachs-Wolfe) plateau at low multipoles, which illustrates the fact that the gravitational potential is “frozen” as long as the modes have not yet entered into the Hubble radius. Second, one expects to find a serie of Doppler peaks at smaller angular scales, produced by acoustic oscillations in the photon-baryon plasma. The height of the first peak depends on almost all the cosmological parameters, but as soon as one considers adiabatic initial conditions and (very) conservative cosmological parameters, the peak is between 2 and 8 times higher than the Sachs-Wolfe plateau. This is a strong prediction of adiabatic models, and it is in good agreement with the current data. (In opposition, a pure isocurvature CDM model leads to a Sachs-Wolfe plateau higher than the first Doppler peak.) In the case of adiabatic and isocurvature mixtures, the CMB anisotropies and the matter power spectrum correspond, on large scales, to different combinations of the initial perturbations. Such a complementarity is all the more useful in our model that, contrarily to the adiabatic case, it does not generically predict the ratio of amplitude between the CMB and the matter power spectrum. Indeed, in the standard adiabatic case, it is a classic calculation to derive the temperature anisotropy as a function of the gravitational potential. In the long wavelength limit, the temperature anisotropies are one third of the gravitational potential, which has varied of a factor  $\simeq 9/10$  during the radiation-to-matter transition. In the case of CDM hybrid perturbations, this relation can be rewritten as :

$$\frac{\delta T}{T} \Big|_{\text{MD}} = \frac{3}{10} \left( 1 + \frac{4}{15} \Omega_\nu^{\text{RD}} - \frac{2}{5} \lambda \Omega_c^{\text{MD}} \right) \Phi_{\text{RD}}, \quad (3)$$

where  $\Omega_c$  and  $\Omega_\nu$  are respectively the CDM and neutrino density parameters, and the indexes RD and MD mean that one considers the quantities during the radiation dominated and the matter dominated eras respectively. The relative amplitude of CMB anisotropies and matter

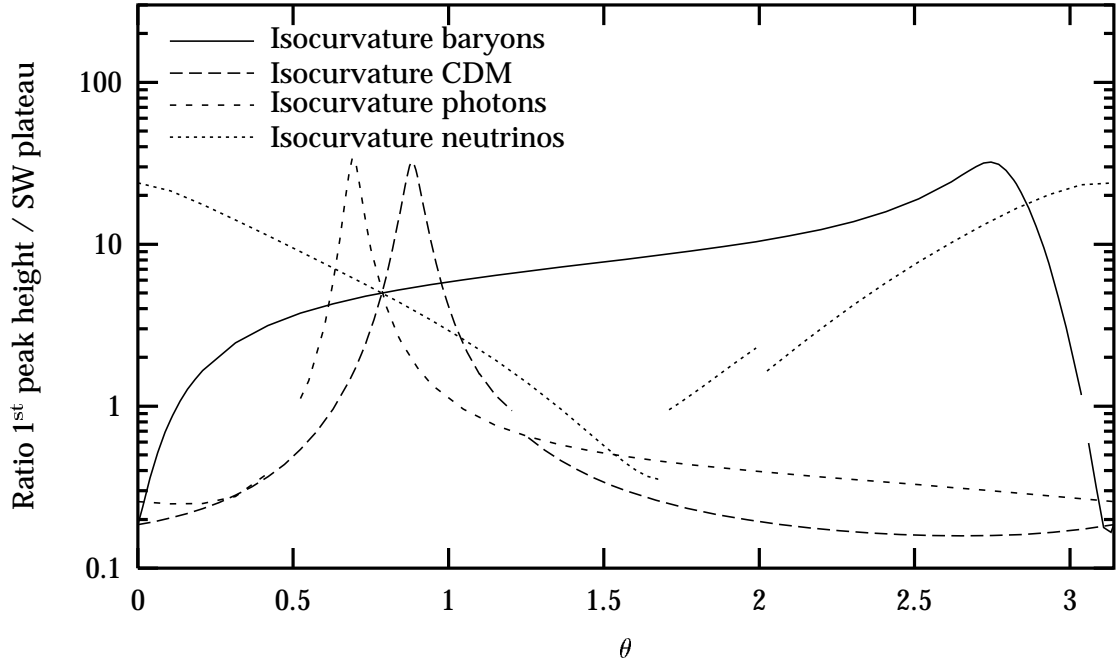


Figure 1: Ratio of the height of the first Doppler peak to the Sachs-Wolfe plateau in the four hybrid models. We have introduced the variable  $\theta$ , defined as  $\delta_X \equiv \delta_X^{\text{adia}} \cot \theta$ , where  $\delta_X^{\text{adia}}$  is the value of the density contrast of the species  $X$  which deviates from adiabaticity in the corresponding adiabatic model. The other cosmological parameters are those of the SCDM model.

power spectrum can therefore in principle be used to extract the isocurvature part of the initial conditions.

#### 4 Numerical results

We have extensively studied the four hybrid perturbations in a recent paper<sup>3</sup>. The main result of our analysis is that the CMB anisotropy and the matter power spectra are rather strongly sensitive to the set of initial conditions we have considered. As a consequence, such models are already fairly well constrained : one cannot deviate strongly from adiabaticity. As an example, we have plotted on Fig. 1 the relative height of the first Doppler peak in the four hybrid models one can consider. Photon and CDM hybrid perturbations are the most constrained. As for the relative amplitude between the CMB anisotropies and the matter power spectrum, we have compared them on Fig. 2. It is clear that the amplitude of the first Doppler peak, which is already well measured by several ground and balloon experiments, is strongly sensitive to the parameter  $\lambda$ . This might help to discriminate between these models and the standard adiabatic model.

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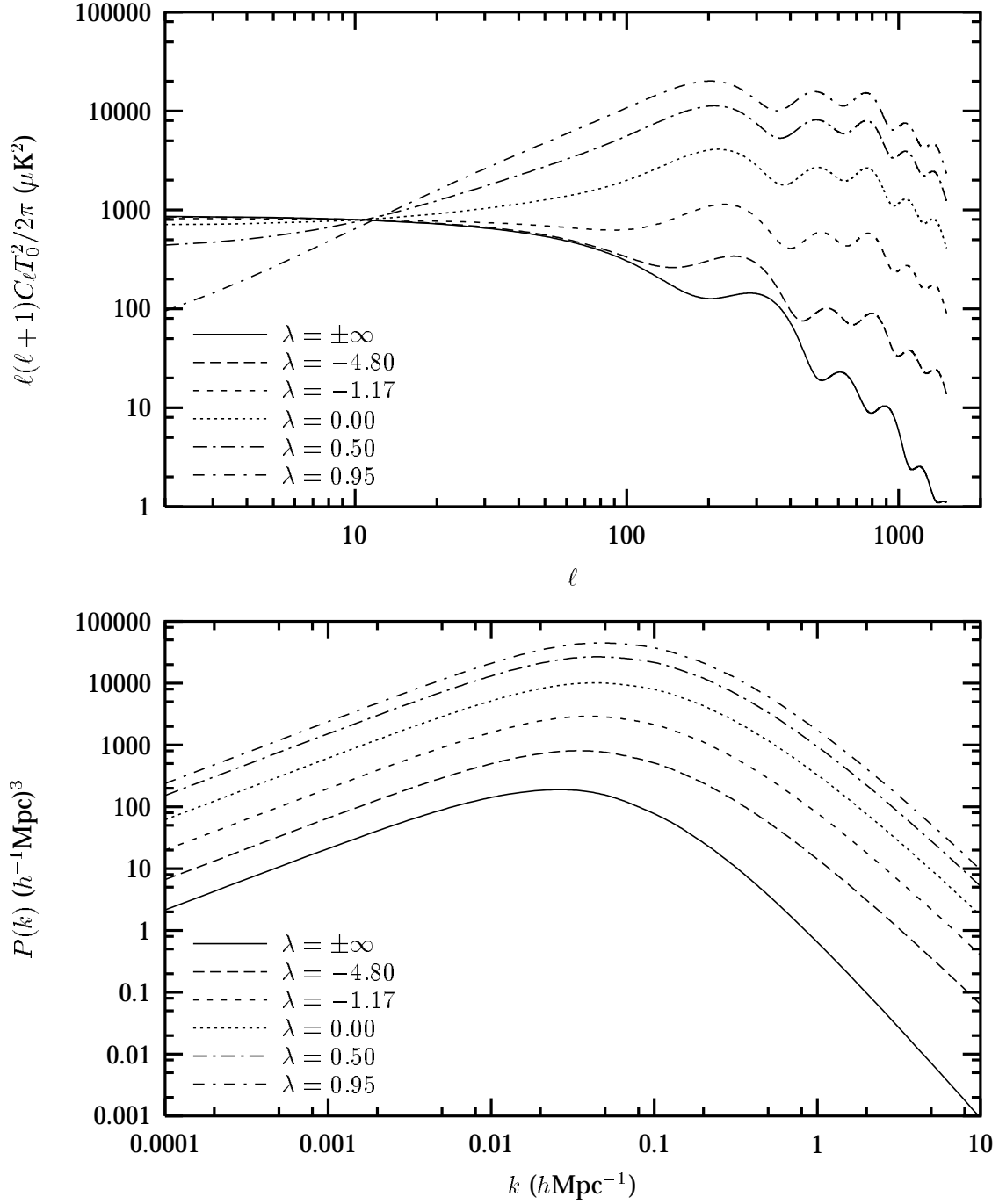


Figure 2: Comparison of the CMB anisotropy (top) and matter power spectra (bottom) in various hybrid CDM models. All the models have been COBE-normalised. Note the difference between the Doppler peak height relatively with the Sachs-Wolfe plateau, as well as the different normalisation of the matter power spectrum. The position of the Doppler peaks as well as the position of the maximum in the matter power spectrum also slightly vary with the parameters.

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