Cosmological constraints in $\Lambda$-CDM and Quintessence paradigms with Archeops

Marian Douspis$^a$,$^1$
Alain Riazuelo$^b$, Yves Zolnierowski$^{c,d}$, Alain Blanchard$^c$
& the Archeops collaboration

$^a$Astrophysics, Keble Road, OX1 3RH Oxford (UK)
$^b$CEA/DSM/SPhT, CEA/Saclay, F–91191 Gif-sur-Yvette cédex (France)
$^c$LAOMP, 14 Avenue E. Belin, F–31400 Toulouse (France)
$^d$LAPP, IN2P3-CNRS, BP 110, F–74941 Annecy le Vieux (France)

Abstract

We review the cosmological constraints put by the current CMB experiment including the recent ARCHEOPS data, in the framework of $\Lambda$-CDM and quintessence paradigm. We show that well chosen combinations of constraints from different cosmological observations lead to precise measurements of cosmological parameters. The Universe seems flat with a 70 percents contribution of dark energy with an equation of state very close to those of the vacuum.

Key words: cosmology, Cosmic microwave background, cosmological parameters

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1 Introduction

The determination of cosmological parameters has always been a central question in cosmology. In this respect the measurements of the Cosmological Microwave Background (CMB) anisotropies on degree angular scales has brought one of the most spectacular results in the field: the flatness of the spatial geometry of the Universe, implying that its density is close to the critical density.

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Although, during the last twenty years the evidence for the existence of non-baryonic dark matter has strongly gained in robustness, observations clearly favour a relatively low matter content somewhere between 20 and 50% of the critical density, indicating that the dominant form of the density of the universe is an unclustered form. Furthermore, the observations of distant supernovae, at cosmological distance, provide a direct evidence for an accelerating universe, which can possibly be explained by the gravitational domination of a component with a relatively large negative pressure: \( P_Q = w_Q \rho_Q \) with \( w_Q < -1/3 \). The cosmological constant \( \Lambda \) (for which \( w_\Lambda = -1 \)) is historically the first possibility which has been introduced and which satisfies this requirement. However, the presence of a non-zero cosmological constant is a huge problem in physics due to the “coincidence problem”. In this paper we shortly summarise the different sets of data and methods used to constrain cosmological parameters. We then conclude by showing the results on cosmological parameters in both \( \Lambda \)-CDM and quintessence paradigms. Such results are presented in details in Benoît et al. 03b and Douspis et al. 03a [1].

2 Method and data

In the following, we make use of the most recent data available on the CMB as well as on other relevant cosmological quantities in order to examine constraints that can be set on cosmological parameters. We assume Gaussian adiabatic fluctuations and a vanishing amount of gravitational waves. Identically, a possible hot dark matter component is neglected in the following. We investigate two cosmological parameters sets: \( \theta_1 = (\Omega_{tot}, \Omega_\Lambda, \Omega_b h^2, h, n, Q, \tau) \) for the \( \Lambda \)-CDM framework and \( \theta_2 = (\Omega_Q, w_Q, \Omega_b h^2, h, n, \sigma_8) \) for the quintessence paradigm. For the latter, we assume a flat Universe with no reionisation and that \( w_Q = \text{Const} \) throughout all the epochs of interest. In order to use CMB data, we first reconstruct the likelihood function of the various experiments. We follow the technique developed in [2] and used in [1,2], by constructing a large \( C_\ell \) power spectra database (CAMB: [5]). We proceed by estimating cosmological parameters from the likelihood functions reconstructed as described in [1]. We compute the value of the likelihood considering the actual band powers dataset of COBE, BOOMERANG, DASI, MAXIMA, VSA, CBI, Archeops ([3]) on each model of our grid. For the different combinations, we consider HST determination of the Hubble constant and supernovæ determination of \( \Omega_m \) and \( \Lambda \) ([4]). Then, for the quintessence paradigm case we used the estimations of \( \sigma_8 \) leading to low values ([6]), by considering: \( \sigma_8 \Omega_m^{0.38} = 0.43 \pm 10\% \) (68% C.L) because the cluster normalisation of the spectrum is highly sensitive to the quintessence scenario.
3 Cosmological Parameter constraints in Λ-CDM paradigm

3.1 Archeops

We first find constraints on the cosmological parameters using the Archeops data alone. The cosmological model that presents the best fit to the data has a $\chi^2_{\text{gen}} = 6/9$. Figure 1 gives confidence intervals on different pairs of parameters. The Archeops data constrain the total mass and energy density of the Universe ($\Omega_{\text{tot}}$) to be greater than 0.90, but it does not provide strong limits on closed Universe models. Fig. 1 also shows that $\Omega_{\text{tot}}$ and $h$ are highly correlated. Adding the HST constraint for the Hubble constant leads to the tight constraint $\Omega_{\text{tot}} = 0.96^{+0.09}_{-0.04}$ (full line in Fig. 1), indicating that the Universe is flat.

Using Archeops data alone we can set significant constraints neither on the spectral index $n$ nor on the baryon content $\Omega_b h^2$ because of lack of information on fluctuations at small angular scales.

![Fig. 1. Likelihood contours in the $(\Omega_\Lambda, \Omega_{\text{tot}})$ (left) and $(H_0, \Omega_{\text{tot}})$ (right) planes using the Archeops dataset; the three coloured regions (three contour lines) correspond to resp. 68, 95 and 99% confidence levels for 2-parameters (1-parameter) estimates. Black solid line is given by the combination Archeops + HST, see text.](image)

3.2 Archeops and other CMB experiments

By adding the experiments listed in section 2 we now provide the estimate of the cosmological parameters using CMB data only. The constraints are shown on Fig. 2 and 3 (left). The combination of all CMB experiments provides $\sim 10\%$ errors on the total density, the spectral index and the baryon content.
respectively: $\Omega_{\text{tot}} = 1.15^{+0.12}_{-0.17}$, $n = 1.04^{+0.10}_{-0.12}$ and $\Omega_b h^2 = 0.022^{+0.003}_{-0.004}$. These results are in good agreement with recent analyses performed by other teams. As shown in Fig. 2 the spectral index and the optical depth are degenerate. Fixing the latter to be $\tau < 0.20$, leads to stronger constraints on both $n$ and $\Omega_b h^2$. With this constraint, the preferred value of $n$ becomes slightly lower than 1, $n = 0.96^{+0.03}_{-0.04}$, and the constraint on $\Omega_b h^2$ from CMB alone is not only in perfect agreement with BBN determination but also has similar error bars, $\Omega_b h^2_{(\text{CMB})} = 0.021^{+0.002}_{-0.003}$. It is important to note that many inflationary models (and most of the simplest of them) predict a value for $n$ that is slightly less than unity (see, e.g., [7] for a recent review).

### 3.3 Adding non–CMB priors

In order to break some degeneracies in the determination of cosmological parameters with CMB data alone, priors coming from other cosmological observations are now added. The results with the HST prior are shown in Figure 3 (right). Considering the combination Archeops + CBDMVC + HST, the best model is $(\Omega_{\text{tot}}, \Omega_\Lambda, \Omega_b h^2, h, n, Q, \tau) = (1.00, 0.7, 0.02, 0.665, 0.945, 19.2\mu K, 0.)$ with a $\chi^2_{\text{gen}} = 41/68$. The constraints on $h$ break the degeneracy between the total matter content of the Universe and the amount of dark energy as discussed in Sect. 3.1. The constraints are then tighter as shown in Fig. 3 (right), leading to a value of $\Omega_\Lambda = 0.73^{+0.09}_{-0.07}$ for the dark energy content, in agreement with supernovæ measurements if a flat Universe is assumed.
Fig. 3. Likelihood contours in the $(\Omega_{\text{tot}}, \Omega_\lambda)$. Left: constraints using Archeops+CBDMVC datasets. Right: adding HST prior for $H_0$.

4 Cosmological Parameter constraints in Quintessence paradigm

4.1 CMB alone

Constraints given by the CMB on some of our investigated parameters are shown in Fig. 4. Considering only CMB constraints leads to degeneracies between parameters. Fig. 4 shows the case of one parameters, $n$, which is not affected by the assumed equation of state of the dark energy ($\Omega_b$ is not either). The preferred value and error bars are $n = 0.95 \pm 0.05$ (68% C.L.) and $\Omega_b h^2 = 0.021 \pm 0.003$. Using CMB alone leaves the 2-parameters space $(\Omega_Q, w_Q)$ almost unconstrained. In our analysis, we found that with the improvement of CMB data obtained by the addition of Archeops band powers reduces appreciably the contours of constraints on the quintessence parameters as well as on cosmological parameters because of the position and the amplitude of the first acoustic peak are better determined, but still does not allow to break the degeneracies.

4.2 Adding Non CMB priors

In order to break the degeneracy it is clearly necessary to consider the additional information on the normalisation of the spectrum by the value of $\sigma_8$, which is highly sensitive to the equation of state (see section 2 of Douspis et al.
Fig. 4. Present CMB dataset likelihood contours in the quintessence paradigm. The sharpness of contours at $\Omega_Q = 0.9$ is due to grid effect.

Fig. 5. Likelihood contours with CMB + all priors in the quintessence paradigm. We can furthermore consider the angular distance coming from distant supernovae. Assuming a flat cosmology, the information on the luminosity of the supernovae can be expressed in term of constraints on the dark energy density and equation of state. Finally the Hubble constant determination by HST Key project is also considered. Combining all the priors finally allows to put strong constraints on both quintessence parameters (Fig. 5): $\Omega_Q = 0.70^{+0.10}_{-0.17}$, $w_Q = -1^{+0.25}_{-0.25}$ (95% C.L.) and finally breaks the $(H_0, \Omega_Q)$ degeneracy.

As a main result, it appears that the classical $\Lambda$-CDM is then comforted and given the priors we used there is no need for quintessence to reproduce the present data.
5 Conclusion

We have studied the constraints that can be obtained on cosmological parameters within the Λ-CDM and the quintessence paradigms by using various combination of observational data set.

Our analysis method has been to investigate contours in 2D parameters space. Such an approach allows to examine possible degeneracies among parameters which are not easy to identify when constraints are formulated in term of single parameter. For instance we found that CMB data alone, despite the high precision data obtained by Archeops do not require the existence of a non-zero contribution of quintessence, because of the degeneracy with the Hubble constant: in practise CMB data leave a large fraction of the $\Omega_Q - w_Q$ plane unconstrained, while only a restricted region of the $\Omega_Q - H_0$ is possible. On the contrary we found that almost no correlation exist with the baryonic content $\Omega_b$ nor the primordial index $n$. In order to restrict the parameter space of allowed models we have applied several different constraints. Interestingly, we found that the amplitude of the dark matter fluctuations, as measured by clusters abundance or large scale weak lensing data can potentially help to break existing degeneracies, although existing uncertainties, mainly systematics in nature do not allow firm conclusion yet. Clearly this will be an important check of consistency in the future. We have then added constraints from Supernovae data as well as HST estimation of the Hubble constant in order to break existing degeneracies. This allows us to infer very tight constraints on the possible range of equation of state of the dark energy. Probably the most remarkable result is that no preference for quintessence does emerge from existing CMB data.

References

[1] Benoît, A. et al. 2003, A&A, 399, L25 (Archeops collaboration), Douspis M. et al. 2003a , A&A in press, astro-ph/0212097
[2] Bartlett, J. G., Douspis, M., Blanchard, A., & Le Dour, M. 2000, A&AS, 146, 507, Douspis M., Bartlett J.G. & Blanchard A., 2003, A&A in press
[3] Benoît, A. et al. 2003, A&A, 399, L19, Halverson, N. W. et al. 2002, MNRAS, 568, 38, Lee, A. T. et al. 2001, ApJ, 561, L1, Netterfield, C. B. et al. 2002, ApJ, 571, 604, Pearson, T. J. et al. 2002, astro-ph/0205388 , Scott, P. F. et al. 2002, astro-ph/0205380, Tegmark, M. 1996, ApJ, 464, L35
[4] Freedman, W. L., Madore, B. F., Gibson, B. K., et al. 2001, ApJ, 553, 47, Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ, 517, 565 & http://www-supernova.lbl.gov
[5] Lewis, A., Challinor, A., & Lasenby, A. 2000, ApJ, 538, 473
[6] Reiprich, T. H. & Böhringer, H. 2002, ApJ, 567, 716
Seljak, U, astro-ph/0111362
Viana, P. T. P., Nichol, R. C., & Liddle, A. R. 2002, ApJ letters, 569, L75

[7] Lyth, D. H. & Riotto, A. 1999, Phys.Rep., 314, 1