

CHARTING THE NEW FRONTIER OF THE COSMIC MICROWAVE BACKGROUND POLARIZATION

F. R. Bouchet¹, A. Benoît & Ph. Camus², F. X. Désert³, M. Piat⁴ and N. Ponthieu⁵

Abstract. The anisotropies of the cosmic microwave background are a gold mine for cosmology and fundamental physics. ESA's Planck satellite should soon extract all information from the temperature vein but will be limited concerning the measurement of the degree of polarization of the anisotropies. This polarization information allows new independent tests of the standard cosmological paradigm, improves knowledge of cosmological parameters and last but not least is the best window available for constraining the physics of the very early universe, particularly the expected background of primordial gravitational waves. But exploiting this vein will be a challenge, since the sensitivity required is *at least* 10 times better than what Planck might achieve at best, with the necessary matching level of control of all systematics effects, both instrumental and astrophysical (foregrounds). We here recall the cosmological context and the case for CMB polarization studies. We also briefly introduce the SAMPAN project, a design study at CNES that aims at detecting the primordial gravitational wave background for a tensor to scalar ratio T/S as small as 10^{-3} .

The Cosmological paradigm. The spatial distribution of galaxies revealed the existence of large scale structures in the Universe, clusters of size ~ 5 Mpc, filaments connecting them, and voids of size ~ 50 Mpc. Their existence and statistical properties can be accounted for by the development of primordial fluctuations by gravitational instability. The current paradigm is that these fluctuations were generated in the very early Universe, probably during an inflationary period, that they evolved linearly during a long period, and more recently reached density contrasts high enough to form bound objects.

¹ IAP, 98bis Bd. Arago, 75014 PARIS, France

² CRTBT, 25 av. des Martyrs, F-38042 Grenoble, France

³ LAOG, BP 53, 414 rue de la piscine, F-38041 Grenoble, France

⁴ APC-Collège de France, 11 place M. Berthelot, F-75231 PARIS

⁵ IAS, Bat. 121, Université Paris-Sud, F-91405 ORSAY

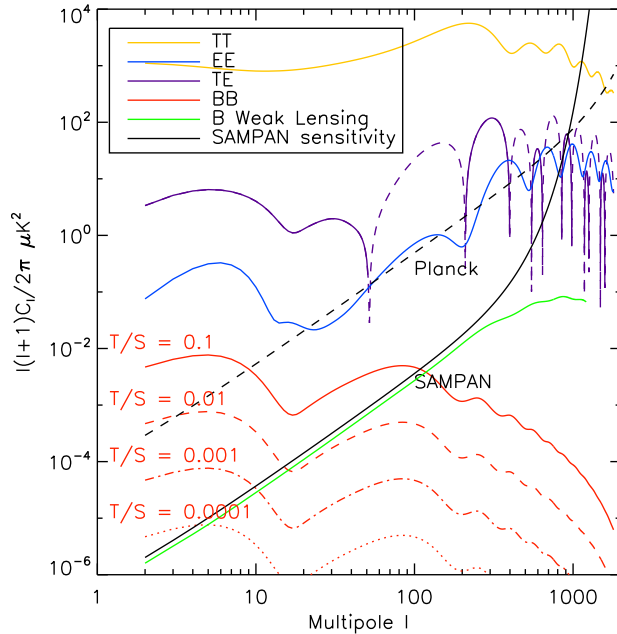


Fig. 1. Angular power spectra of the temperature and polarization anisotropies of the CMB for the Λ CDM model that best fits the WMAP first year data. The B mode spectrum is presented for different Tensor-to-Scalar ratios $T/S = 0.1$ to 0.0001 , i.e. for an inflation energy scale $E_{infl} \simeq 2.2 \cdot 10^{16}$, $1.2 \cdot 10^{16}$, $6.8 \cdot 10^{15}$, $3.8 \cdot 10^{15}$ GeV. The E modes transformed into B modes by weak-lensing are in green. The SAMPAN target sensitivity ($5\mu K \cdot \text{arcmin}$) is in solid black and can be compared with that of Planck in black dashes. SAMPAN should be able to detect the primordial B mode polarization down to $T/S \simeq 0.001$ on very large angular scales.

The anisotropies of the CMB are the imprint of these fluctuations as they were¹ when photons last interacted with baryonic matter, when the Universe became neutral at a redshift of 1100 (the Universe was then $\sim 370\,000$ years old). Since at that time the fluctuations are still tiny, all the evolution till then is linear and can be computed quite accurately. Despite some degeneracies, the value of most parameters can in principle be inferred from sufficiently accurate measurement of the angular power spectra C_ℓ of the CMB temperature and polarization anisotropies. The CMB polarization fluctuations are due to the last Thomson scatterings of the photons on free electrons that see an inhomogeneous (quadrupolar) incoming radiation field.

¹But for a small correction due to the photons propagation through the developing large scale structures.

The CMB polarization. The main source of these quadrupoles is the very same density (and associated velocity) perturbations that source the temperature anisotropies. This particular state of polarization (E) is therefore correlated to temperature. An accurate measure of E enables to break degeneracies between the effects of some parameters, for instance that between the reionization optical depth and the scalar perturbation spectral index. The E mode polarization has already been detected (3, 8, 1, 9, see Fig. 1) and should be further characterized by forthcoming experiments (for a review, see 7). A second source of polarization of the CMB are tensorial perturbations such as those from a background of Gravitational Waves generated during Inflation (hereafter IGW). The induced polarization pattern is of odd parity (E was of even parity because density fluctuations are scalar) and has been named B in analogy with electromagnetic fields (11). No other primordial source than the IGW could generate B type polarization. Its detection would therefore be a signature of the IGW background. A measurement of the amplitude of the B mode power spectrum gives a direct estimation of the energy scale of inflation. Interestingly enough, CMB polarization experiments can probe E_{inf} at the typical GUT scale, which means that they have a strong constraining power on the relation between inflation and GUT, which has implications not only in Cosmology but also in High Energy Physics. This is way beyond the capabilities of next generation gravitational interferometers. A challenge that a CMB polarization experiment faces is the ability to remove foregrounds emission (see below). Another challenge would be to actually subtract the part of E mode power which is transformed into B modes though their (weak) lensing by large scale structures (4). While possible in principle, this calls for very high sensitivity and angular resolution, but it would then allow the detection of weaker B -contributions.

The detection of the B mode polarization requires large improvements on instrumental sensitivity, systematic effects and foregrounds control. Indeed, the desired sensitivity is 10 to 30 times better than Planck should do. Since detectors are already nearly photon noise limited, the only solution is to increase their number in the focal planes and to go up to several 10,000s which has dramatic implications in terms of electronics, cryogenics and telemetry. This is the goal of the ongoing bolometer array developments.

The SAMPAN project. One may then ask what would be the best experimental design to detect the B modes? The gravity wave signal is on large angular scales ($\theta > 1$ deg). The resolution is therefore not an issue in itself and a subdegree beam would do (if one does not attempt to clean the B map from its lensed E mode contribution). On the other hand, the coverage of the sky should be as complete as possible, since 1) B modes are largest on large scales, 2) increasing coverage decreases cosmic variance 3) missing information impinges the decomposition of polarisation into separate E and B modes.

The polarization of foregrounds is a serious issue for CMB studies, especially for polarization. Recent results from Archeops (2, 6) have shown that the thermal emission from dust is significantly polarized on large angular scales. To control

this radiation field, several frequency channels are required. The 100, 143, 217 and 353 GHz bands, advocated for Planck, optimize the sensitivity to the CMB and should enable to remove the dust contribution at the best possible level.

SAMPAN (*S*Atellite to *M*easure the *P*olarized *A*Nisotropies) is a mini-satellite project at CNES to be launched after 2012 to an L2 orbit. It is currently in “phase 0” of preliminary design study. The goal is to have 20 000 polarization sensitive bolometers at 100 mK, divided in the four frequency bands mentioned above, in order to reach a target (combined) CMB sensitivity of $5 \mu\text{K}\cdot\text{arcmin}$. This would enable the detection of the primordial B mode if the Tensor to Scalar ratio is $T/S \gtrsim 0.001$, i.e. the energy scale of inflation $E \gtrsim 6 \times 10^{15}$ GeV. This is close to the limit anticipated for foregrounds removal (10).

In order to have as symmetrical a system as possible, we are studying a refractive telecentric system of at least 20 arcmin resolution FWHM at 217 GHz. The main originality of SAMPAN is its scanning strategy dedicated to have redundancies at many different timescales. First the polarization measurement can be checked by spinning the whole satellite around its main optical axis in a period between 10 and 20 seconds. A precession/nutation motion of the satellite then allows connecting large angular scales within a short time span (40 deg. separation on the sky in a few minutes) and to cover half of the sky in a time scale of few days.

Conclusions: The CMB remains unique in tightening together so many fundamental elements: fundamental physical laws, cosmography and cosmogony, i.e the cosmological paradigm for the Universe content, evolution, structuring, and its parameters. Building such a polarization mission will surely be challenging, but in proportion to the potential pay-offs in addressing such topics as tighter tests of the cosmological paradigm, the primordial gravitational wave background and the energy scale of inflation, or determining neutrinos masses.

References

- Barkats, D., Bischoff, C., Farese, P., et al, 2005, ApJ, 619, 127
 Benoît, A., Ade, P., Amblard, A., et al, 2004, AA, 424, 571
 Kovac, J. M., Leitch, E. M., Pryke, C., et al, 2002, Nature, 420, 772
 L. Knox & Y.-S. Song, 2002, Phys. Rev. Lett., 89, 011393
 Jaffe, A., Kamionkowski, M., Wang, L., 2000, Phys. Rev. D, 61, 083501
 Ponthieu, N., Macías-Pérez, J. F., Tristram, et al, 2005, AA, in press.
 Ponthieu, N., 2005, proceedings of *Sky polarization at far infrared to radio wavelengths: the Galactic screen before the Cosmic Microwave Background*, F. Boulanger, M. A. Miville-Desché nes, Eds.
 Redhead, A. C. S., Myers, S. T., Pearson, T. J., et al, 2004, Science, 306, 836
 Montroy et al, 2005, ApJ, submitted, [astro-ph/0507494](#).
 Tucci, M., Martí nez-Gonzá lez, E., Vielva, P., Delabrouille, J.: 2005, MNRAS, 360, 935
 U. Seljak, M. Zaldarriaga, 1997, Phys. Rev. D, 55, 1830