The CMB polarization: status and prospects

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Abstract

The study of cosmic microwave background (CMB) polarization is still in a pioneering stage, but promises to bring a huge advancement in cosmology in the near future, just as high-accuracy observations of the anisotropies in the total intensity of the CMB revolutionized our understanding of the universe in the past few years. In this contribution, we outline the scientific case for observing CMB polarization, and review the current observational status and future experimental prospects in the field.

1 Introduction

Strong theoretical arguments suggest the presence of fluctuations in the polarized component of the cosmic microwave background (CMB) at a level of 5-10% of the temperature anisotropy. A wealth of scientific information is also expected to be encoded in this polarized signal. However, while the existence of anisotropies in the temperature of the Cosmic Microwave Background (CMB) has now been firmly established and accurately measured by several experiments [1, 2, 3, 4], bringing us high-precision constraints on the parameters of the standard cosmological model, the investigation of the polarized component of CMB anisotropy is still in its infancy.

It is then interesting to review, although briefly, the status of CMB polarization research, both theoretically and observationally. CMB polarization theory is well developed, while observations are complicated and hard to
perform. In this contribution, we attempt to give a coverage of both issues: the basics of CMB polarization theory are outlined in Section 2, while the current and future observational situation is described in Section 3.

2 Theory of CMB polarization

In this section, we outline the basic theoretical framework of CMB polarization, emphasizing the main aspects that make it an appealing target for cosmological investigation. Excellent reviews on the physics of the CMB polarization, exploring the subject with greater detail, are [5, 6, 7].

2.1 Formalism

The polarization properties of the CMB can be best understood using the formalism of Stokes parameters [8]. Consider a nearly monochromatic electromagnetic wave propagating in the $z$ direction, with $x$ and $y$ components of the electric field given by:

\[ E_x = a_x(t) \cos(\omega_0 t - \theta_x(t)), \]
\[ E_y = a_y(t) \cos(\omega_0 t - \theta_y(t)). \]

(1)

Then, the Stokes parameters are defined by:

\[ I \equiv \langle a_x^2 \rangle + \langle a_y^2 \rangle, \]
\[ Q \equiv \langle a_x^2 \rangle - \langle a_y^2 \rangle, \]
\[ U \equiv \langle 2a_x a_y \cos(\theta_x - \theta_y) \rangle, \]
\[ V \equiv \langle 2a_x a_y \sin(\theta_x - \theta_y) \rangle. \]

(2)

where the brackets $\langle \rangle$ represent the average over a time much longer than the period of the wave. The physical interpretation of the Stokes parameters is straightforward. The parameter $I$ is simply the average intensity of the radiation. The polarization properties of the wave are described by the remaining parameters: $Q$ and $U$ describe linear polarization, while $V$ describes circular polarization. Unpolarized radiation (or natural light) is characterized by having $Q = U = V = 0$. CMB polarization is produced through Thomson scattering (see below) which, by symmetry, cannot generate circular polarization. Then, $V = 0$ always for CMB polarization. The amount of linear polarization along the $x$ or $y$ directions is measured by the Stokes parameter $Q$. When $U = 0$, a positive $Q$ describes a wave with polarization oriented along the $x$ axis, while a negative $Q$ describes a wave with polarization oriented along the $y$ axis. Similarly, the Stokes parameter $U$ measures
the amount of linear polarization along the two directions forming an angle of 45° with the $x$ and $y$ axis. This implies that the Stokes parameters $Q$ and $U$ are not scalar quantities. It is straightforward to show that when the reference frame rotates of an angle $\phi$ around the direction of observation, $Q$ and $U$ transform as:

$$
\begin{pmatrix}
Q' \\
U'
\end{pmatrix}
= 
\begin{pmatrix}
\cos 2\phi & \sin 2\phi \\
-\sin 2\phi & \cos 2\phi
\end{pmatrix}
\begin{pmatrix}
Q \\
U
\end{pmatrix}.
$$

(3)

This means that $Q$ and $U$ are not the components of a vector. Mathematically, $Q$ and $U$ are the components of a second-rank symmetric trace-free tensor:

$$
P_{ab} = \begin{pmatrix}
Q & U \\
U & -Q
\end{pmatrix},
$$

(4)

which represents a spin-2 field. For visualization purposes only, one can define a polarization “vector” with amplitude $P = (Q^2 + U^2)^{1/2}$ and orientation $\alpha = 1/2 \tan^{-1} (U/Q)$: this is not properly a vector, since it remains identical after a rotation of $\pi$ around $z$, thus defining an orientation but not a direction.

### 2.2 Physical mechanism

Having introduced the proper formalism, we can focus on the physical mechanism that generates the polarized component of CMB radiation. Before the formation of neutral hydrogen atoms in the primordial universe (a process termed recombination which takes place a few hundred thousand years after the big bang, at redshift $\approx 1100$), the CMB photons closely interact with the free electrons of the primeval plasma through Thomson scattering. The angular dependence of the scattering cross-section is given by:

$$
\frac{d\sigma}{d\Omega} = \frac{3\sigma_T}{8\pi} |\hat{\epsilon} \cdot \hat{\epsilon}'|^2,
$$

(5)

where $\hat{\epsilon}$ and $\hat{\epsilon}'$ are the polarization directions of incident and scattered waves. After scattering, initially unpolarized light has:

$$
I = \frac{3\sigma_T}{16\pi} I' (1 + \cos^2 \theta), \quad Q = \frac{3\sigma_T}{16\pi} I' \sin^2 \theta, \quad U = 0.
$$

(6)

Decomposing the incident radiation in spherical harmonics and integrating over all incoming directions gives:

$$
I = \frac{3\sigma_T}{16\pi} \left[ \frac{8}{3} \sqrt{\pi} a_{00} + \frac{4}{3} \sqrt{\frac{\pi}{5}} a_{20} \right], \quad Q - iU = \frac{3\sigma_T}{4\pi} \sqrt{\frac{2\pi}{15}} a_{22}.
$$

(7)
Then, polarization is only generated when a quadrupolar anisotropy in the incident light at last scattering is present. This has two important consequences. Because it is generated by a causal process, CMB polarization peaks at scales smaller than the horizon at last scattering. Moreover, the degree of polarization depends on the thickness of last scattering surface. As a result, the polarized signal for standard models at angular scales of tens of arcminutes is about 10% of the total intensity (even less at larger scales). Typically, this means a polarized signal of a few \( \mu \text{K} \).

2.3 Statistics

In order to connect the observed polarized signal to theoretical prediction, it is convenient to expand the polarization tensor in terms of two scalar fields: a so-called electric (or gradient) field, \( E \), and a magnetic (or curl) field, \( B \). This is analogous to the decomposition of a vector into a gradient and divergence-free vector. These fields can then be expanded into spherical harmonics just as it is done with the temperature field, as:

\[
P_{ab} = T_0 \sum_{l=2}^{\infty} \sum_{m=-l}^{l} \left[ a_{(lm)}^E Y_{lm}^{E} + a_{(lm)}^B Y_{lm}^{B} \right]
\]

where the generalization of spherical harmonics for arbitrary spin has been used \[^9\]. The statistical properties of the CMB anisotropies polarization are then characterized by six power spectra: \( C_T^l \) for the temperature, \( C_E^l \) for the E-type polarization, \( C_B^l \) for the B-type polarization, \( C_{TE}^l \), \( C_{TB}^l \), \( C_{EB}^l \) for the cross correlations. Each of the power spectra is computed in the usual way from the spherical harmonic coefficients, as:

\[
\langle a_{lm}^X a_{l'm'}^X \rangle = C_X^{X'} \delta_{ll'} \delta_{mm'}
\]

For the CMB, \( C_{TB}^l = C_{EB}^l = 0 \). Furthermore, since \( B \) relates to the component of the polarization field which possesses a handedness, one has \( C_B^l = 0 \) for scalar density perturbations. The detection of a non zero \( B \) component would then point to the existence of a tensor contribution to density perturbations. An example of theoretical power spectra is shown in Figure \[2\]

The relation relating \((E,B)\) to \((Q,U)\) has a non-local nature. This can be easily seen in the limit of small angles, where it can be written as:

\[
E(\theta) = -\int d^2\theta' \omega(\tilde{\theta}) Q_r(\theta'), \\
B(\theta) = -\int d^2\theta' \omega(\tilde{\theta}) U_r(\theta'),
\]

\[^9\]
where the 2D angle $\theta$ defines a direction of observation in the coordinate system perpendicular to $z$,

$$Q_r(\theta) = Q(\theta') \cos(2\tilde{\phi}) - U(\theta') \sin(2\tilde{\phi}),$$

$$U_r(\theta) = U(\theta') \cos(2\tilde{\phi}) + Q(\theta') \sin(2\tilde{\phi}).$$

and $\omega(\tilde{\theta})$ is a generic window function.
2.4 CMB polarization as a cosmological tool

The polarization power spectrum for the $E$ mode shows the same kind of acoustic features that are now well known to exist in the temperature anisotropy spectrum. The peaks in polarization, however, are out of phase with those in the temperature: $E$ mode polarization has maximum intensity were the temperature is at a minimum, and vice versa. This is due to the fact that polarization is generated by quadrupolar anisotropy at last scattering, and this is closely related to the velocity of the coupled photon-barion fluid. The maximum compression of rarefaction (and minimum velocity) of the fluid corresponds to peak in the temperature anisotropy (and troughs in the polar-
Figure 3: Top panel – Temperature power spectra for a standard CDM model (solid line), and the same CDM model with a fraction of the critical density coming from a cosmological constant (dotted line). If we add to the latter a contribution from tensor perturbations (gravitational waves background) and reionization (dashed line) we can make it indistinguishable from the standard CDM model. Bottom panel – The same models and their polarization power spectra. The CDM model can be identified by its polarized signal, because it does not generate a B-type component.
A large amount of valuable cosmological information can be extracted from the observation of CMB polarization. Since it probes the epoch of decoupling, polarization allows one to perform detailed tests of the recombination physics. In particular, it is a well known fact that the universe underwent a phase of reionization at redshifts of at least $z \sim 5$, during the formation of early cosmic structure. The investigation of this so-called dark ages is an active subject of investigation [10]. The CMB temperature anisotropy signal gets damped when the photons are diffused by free electrons along the line of sight. The amount of damping would be a powerful probe of the optical depth to reionization. However this effect is masked by other physical mechanisms. For example, there is a strong degeneration with the spectral index of primordial perturbations. CMB polarization would prove very powerful in removing these degeneracies: if the optical depth is non zero, a recognizable polarization signature gets generated at large angular scales, allowing to investigate the detailed reionization history, discriminating models that have the same optical depth but a different evolution of the ionization fraction with redshift [11]. Not only the characterization of the detailed ionization history of the universe would have a strong scientific impact, but it would also greatly increase the accuracy of the determination of other cosmological parameters, such as the above mentioned spectral index of scalar primordial perturbations. This, in turn, would be extremely important when constraining models of inflation.

One crucial aspect of CMB polarization has to do with the properties of its $B$ component. The consequences of detecting $B$ polarization for theoretical models would be enormous. $B$ modes, as mentioned above, can only be generated when a tensor component of primordial perturbations is present (namely, a background of primordial gravitational waves). This is precisely one of the prediction of inflationary scenarios. The ratio of scalar to tensor fluctuations $r$, related to the amplitude of $B$ modes, is a direct signature of the inflation energy scale. On the other hand, observing the $B$ component is the hardest challenge faced by experimentalists, since the signal is expected to be extremely faint, and possibly contaminated by diffuse galactic emission. Furthermore, the $B$ spectrum should peak at large angular scales (the most affected by cosmic variance) and can be contaminated by spurious leakage from $E$ modes when the observed area does not cover the entire sky. The level of $B$ signal also depends very strongly on the epoch and amount of reionization, so that the predictions of detectabilities are affected by the assumptions made on the ionization history of the universe. Finally, weak lensing from large scale structure in the local universe affects the distribution of CMB photons (resulting in a so-called cosmic shear). This can induce a curl component in the polarization signature, that can be wrongly interpreted
as evidence for non zero $B$ modes, or act as a background that would make the tensor primordial contribution impossible to detect [12]. Techniques to detect and remove the shear contribution have been developed and should prove effective when dealing with future data [13]. The shear contribution has also a scientific interest in itself, since it has been shown [14] that it can lead to a determination of the neutrino mass from measurements of CMB temperature and polarization alone.

3 Detecting CMB polarization

3.1 Past and present

It has been realized as early as 1968 [15] that, close to decoupling, Thomson scattering would induce a small degree of linear polarization on unpolarized but anisotropic CMB photons. However, the weakness of this contribution has prevented its detection until very recent times. Over three decades of experimental efforts have resulted in a quite lengthy series of upper limits (e.g. [16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 24]) some of which are displayed in Fig. 4. These limits speak of a steady increase towards the level of the polarization anisotropy, a quest well motivated by the understanding — that had become clear along road — of the wealth of cosmological information encoded in the polarization power spectra.

The long pioneering phase was ended by the DASI [29] detection of a TE and EE signal in 2002. DASI is a ground based interferometer located at the South Pole Amundsen-Scott research station. When configured as a polarimeter, it has sensitivity to all four Stokes parameters, and has been optimized to study CMB anisotropy in the range $140 \lesssim \ell \lesssim 900$ [28]. The first release has reported a detection of EE mode polarization with an rms amplitude of $0.8 \mu K$ at $4.9 \sigma$ and a $\sim 2\sigma$ detection of TE, values strengthened to $6.3 \sigma$ ($2.9 \sigma$) for EE (TE) in the more recent three years release [30].

Following DASI, other experiments have claimed EE detection; CAPMAP, an evolution of the PIQUE system [32], using coherent HEMT receivers at 100 GHz coupled to a large dish to achieve high (3.6') angular resolution, has reported marginal ($2.3 \sigma$) detection of EE [31]. CBI (Cosmic Background Imager), a radio interferometric receiver working in the band 26-36 GHz and covering a wide range of multipoles ($300 \lesssim \ell \lesssim 3500$) has reported the most robust EE detection to date on small angular scales, at $8.9 \sigma$ [33]. The Wilkinson Microwave Anisotropy Probe (WMAP) satellite has measured TE correlations with high $\ell$ resolution at many $\sigma$ as of the first data release of 2003 [34]. As it is well known, WMAP is a satellite flown by NASA featuring
HEMT radiometers arranged in differential assemblies; it observes the sky in four microwave bands, Kα, Q, V and W. The three year WMAP release [35] has improved significantly its TE measure, particularly at the lowest multipole probed, sensitive to the CMB photon’s optical depth \( \tau \). Furthermore, it has provided an EE detection, again especially effective at the (hitherto untested) lowest multipoles, given the combination of the WMAP large sky coverage and modest sensitivity (as far as CMB polarization is concerned).
The above experiments have detected EE modes (and, in some cases, TE correlations) by using coherent detectors. Measures of CMB polarization using uncoherent detectors (namely, bolometers) have been delivered by BOOMERanG 03, a balloon borne experiment featuring a new generation of bolometers dubbed PSB (Polarization Sensitive Bolometers), flown in 2003 from the McMurdo Antarctic base. Analysis of the flight data have provided high quality measurements of TE and EE CMB spectra. The current situation of EE measurements is displayed in Fig. 5.
3.2 Current implications for cosmology

The present status of CMB polarization observations does not allow a determination of cosmological parameters at the same level of accuracy obtainable using temperature anisotropies. The most useful cosmological result established using CMB polarization data is, currently, one of consistency: the standard cosmological model (a universe with flat geometry, dominated by dark matter and dark energy of unknown nature, and consistent with the basic predictions of the inflationary scenario) predicts a level of CMB polarization that is not ruled out by observations, and actually seems to be of the right intensity to match the present data. Intriguingly, the peak and through positions in the E polarization spectrum seems to fall in the right places to match the predictions of the adiabatic primordial perturbation scenario (see, e.g. [39]. The level of B polarization is well within the upper limits derived from the observations. These results lend further support to the basic cosmological scenario — although they are undoubtedly in need of stronger confirmations.

Perhaps, the strongest cosmological constraints from CMB polarization are currently indirect ones. For example, when the WMAP EE data are taken into account, they help to exclude a significant set of values for the optical depth to reionization. Claims of a very early reionization epoch from the first year release of WMAP data [40] were essentially driven by a large TE correlation detected at large angular scales: this has now dramatically changed, once better data from three years of observations and new constraints on E modes were taken into account [41]. Better constraints on \( \tau \) have, in turn, had a consequence for the determination of the primordial spectral index, since the degeneracy between \( \tau \) and \( n_s \) got significantly reduced.

To summarize, the CMB polarization looks currently very promising as a tool to constrain cosmological models, but observations are not at the level of accuracy needed to push the envelope of parameter determination. Clearly, much better data are needed, particularly in the area of B modes, still almost unexplored.

3.3 Experimental concerns

Before CMB polarization measurements can be turned into an high precision cosmological tool, thorough understanding of many experiment related issues is required. In comparison with intensity anisotropy measurements, significant complications arise.

One obvious issue is detector sensitivity: detecting the CMB E mode polarization requires an instrumental sensitivity a couple of orders of mag-
nitude higher than intensity, and even in the most favorable models the B mode signal is a further order of magnitude below $E$. However, very little room is left for improvement in single detector technology: bolometers used in modern CMB missions (such as BOOMERanG and PLANCK HFI) are already photon noise limited [42], while coherent detectors (e.g., HEMT based radiometers) are not expected to improve significantly in the near future [43]. The only possible way to increase sensitivity is thus by statistical redundancy, increasing the total integration time and/or the number of detectors that populate the focal plane. The former strategy clearly speaks in favor of ground based and space borne missions, although Ultra Long Duration Ballooning (ULDB) CMB aimed flights could be achieved in the near future. In any case, long term stability of highly sensitive instruments is a matter of concern (see below). On the other hand, integration of many detectors on a single focal plane seems to be an unavoidable complication. Concerns here mainly relate to manufacturing costs, since it is unsuitable to mass produce highly sensitive CMB detectors, and, in the case of space borne experiments, power budget availability, since active cooling is likely to be required. In addition, it is unclear how high density focal plane will behave in terms of cross talk between detectors. The current trend is towards photolithographic arrays of bolometers, although techniques are being devised that could make radiometer arrays perfectly feasible and competitive.

Detector sensitivity is not the full story. Not surprisingly, polarization measurements inherit and magnify all the contaminations by systematic effects that have plagued high precision temperature observation. In addition, being polarization a tensor quantity, its measurement strategies are usually more complicated than those adopted for intensity. Hence, a number of polarization specific systematic effects have been predicted — and encountered — that are likely to complicate or even hamper detection, regardless of statistical noise control. The long list includes optics induced polarization (most telescopes used for CMB are off-axis system due to the necessity of controlling sidelobes), band and gain mismatch between detectors, cross polarization (i.e. far from perfect isolation effects) and beam asymmetry, that induces leakage of $I$ into $Q$ and $U$. Furthermore, due to limiting scanning strategy constraints, polarization is usually estimated by joint analysis of several detectors, both in order to gain sensitivity and account for poor redundancy in detector orientation. This fact further complicates the analysis, as optical beam mismatches and detector cross talks become sources of concern. For instance, BOOMERanG 03 had to correct for noise correlated among different detectors [36], while WMAP has encountered problems related to gain variations [43]. The above complications also reflect onto data analysis techniques, which often must be redesigned to tackle polarization...
Our best window for observing the temperature anisotropies lies close to 70 GHz, where foreground emission seems to display a minimum. This has permitted accurate mapping of the CMB intensity pattern, without sacrificing much sky to foregrounds. However, when precision measurements are at the stake, cleaning or component separation techniques are needed (e.g., [46, 47]. *A fortiori*, the same is deemed true for polarization measurements, although not much is known about polarized foreground emission. Archeops has measured polarized emission from dust at 353 GHz both in the Galactic plane [49] and at higher Galactic latitudes [48]. In the latter case, extrapolation of their findings suggest that polarized dust emission will be a major source of concern for measurements above 100 GHz [48]. WMAP found significant contamination from polarized foreground extended to large portions of the sky; the WMAP team analysis shows that a foreground model must be subtracted from the data to obtain meaningful detections of CMB polarization at low ($\ell < 10$) multipoles and that the cleanest window for polarization measurements is located at about 60 GHz [35]. Under the hypothesis that all other statistical and systematic error sources will eventually be tamed, foreground contaminations are likely to dominate the uncertainties in future measurements of the CMB anisotropy pattern, just like what is happening today with intensity. It is also likely that component separation methods will play an important role in the analysis (e.g., [51]).

### 3.4 The near future

Several experimental efforts to measure the polarization of the CMB are en route. A few are currently in operation or in the (often lengthy) process of data analysis, while the majority will are expected to deliver data within the next few years. Hereafter, we list a few experiments, loosely divided by type, without sake of completeness. See [51] for a review.

**Ground based experiments**— Several E modes oriented efforts are still active, including a few mentioned above; however, the tendency is towards the detection of B modes. AMiBA [52], is a dual channel (85 – 105 GHz) interferometric array of (up to) 19 elements, currently being installed at the Mauna Kea (Hawaii) site. Its predicted angular resolution is about 2 arcminutes, and has full polarization capabilities: contrary to most CMB oriented projects, it can also measure the circular polarization Stokes parameter ($V$). BICEP (Robinson Gravitational Wave Background Telescope) [53] is an array featuring 49 pairs of polarization sensitive bolometers already in operation at South Pole. It has an instantaneous field of view of $\sim 17^\circ$, and angular resolutions of $55'$ ($37'$) at 100 (150) GHz. BICEP has the sensitivity to detect...
in three years of observations the peak induced by primordial gravitational waves in the BB spectrum, if \( r \gtrsim 0.1 \). BRAIN and CLOVER are two separate but interlinked (in the sense that they rely on similar hardware) experiments to be deployed at the Dome C observing site, within the French-Italian Concordia Antarctic facility [54]. Dome C is probably the best observing site on Earth for high precision microwave measurements. BRAIN [55] is a new concept bolometric interferometer using six pairs of coupled feed horns operating at 150 GHz and spaced by a few wavelength; BRAIN’s pathfinder experiment is under construction on site. CLOVER [56] is a multiple bolometric array: four arrays each composed of 64 bolometers are at the focal planes of optical assemblies, evenly arranged around the cryostat. There are a total of three telescopes in the range 90 – 220 GHz, its angular resolution for CMB oriented channels being about 15’. CLOVER is scheduled to achieve first light in 2008. QUaD (QUEST at DASI) [58] is another new generation instrument created by mounting the QUEST bolometer array on the DASI telescope. QUEST [57] is an array of 31 bolometers operating between 100 and 150 GHz. Observing up to \( \ell \sim 2500 \), it can measure the contribution to B modes arising from lensed E modes, i.e. the so called cosmic shear. The above instruments are all based on bolometric technology. An example of an experiment that employs an array of coherent detectors (“radiometers on a chip”) is QUIET [60].

**Balloon borne experiments**— The data analysis from BOOMERanG is still ongoing and the balloon could in principle be flown again. MAX-IPOL [59] is another balloon aimed at E modes, featuring a rotating half wave plate in front of bolometric detectors. It has been flown, and a data release is expected soon. Bar-SPORT [63] is an experiment based on coherent detectors to measure the E mode pattern, devised as a test bed for SPORT (see below). Originally planned as a balloon borne telescope, it now seems to have been reconfigured as a ground based effort at Dome C [64]. Among the experiments also aimed at the B modes, EBEX [61] is an effort based on bolometric transition edge detectors; polarization capabilities are achieved through a magnetically levitated half wave plate. The focal plane is shared between four arrays observing at 150, 250, 350 and 450 GHz, for a total of up to 1320 detector elements, with a maximum resolution of 8’. Another B modes oriented balloon, funded by NASA, is PAPPA [62].

**Orbital efforts**— WMAP is obviously still taking data, slowly increasing its sensitivity with time. SPORT [65] is an experiment selected by ESA to be flown on the International Space Station. It is based on coherent detector and directly measures the Q and U Stokes parameters (on a 7° angular scale) by cross correlating two circular components with opposite helicity. Originally scheduled for launch in 2005, it has been delayed (currently, *sine die*) due
to the well known NASA Space Shuttle program difficulties. Planck [67], by many considered the ultimate CMB temperature anisotropy mission, has polarization capabilities in all its coherent (LFI) detectors and in many bolometric (HFI) detectors. The launch is currently scheduled in early 2008. The uniqueness of Planck is in that it will produce Q and U maps over the full sky over a wide range of frequencies (30 – 350 GHz), with the combination of high sensitivity and tight control of systematics that is only achievable from space. However, Planck has not been designed with B modes in mind, and a mission with at least a sensitivity 10 times better is needed to detect $r \sim 0.01$.

### 3.5 Exploiting the B modes: an experimental challenge

It is quite evident that the current goal in CMB science is to measure the B modes and distillate cosmological information out of them. The two hot fronts of this research are the “low” $\ell (\sim 100)$ signal from primordial gravitational waves and the high $\ell$ contribution from lensed E modes. It is likely that, if inflation is a reliable theory and if there are no unforeseen systematic complication, one or more sub orbital efforts among the ones listed above will actually detect these modes. Another question, however, is whether such a detection will prove robust and accurate enough to derive firm consequences for Cosmology. It is a widely accepted argument that only a satellite mission can achieve the correct combination of full sky sampling, sensitivity, thermal stability and spectral coverage that will turn the detection into solid science. In this respect, the many suborbital efforts under development will act as pathfinders, returning invaluable testing of frontier technological devices.

Several post Planck orbital efforts are under study. NASA has solicited proposals for its “Beyond Einstein” program in structure and evolution of the universe; in particular, the request is for a medium size mission code named Inflation Probe, to search for the gravitational wave signature in the CMB. The current Inflation Probe candidate is called CMBPOL [68]. If selected, this mission could be flown as early as 2018. In Europe as well concept studies are being submitted to national agencies, as is the case of the French SAMPAM project [69]. Within a few months, ESA will probably issue a call for proposal for its Cosmic Vision program. It is almost certain that a specific proposal will be submitted by the CMB community for a B modes oriented satellite. Whether this will be for a low $\ell$ or an high $\ell$ mission (capable, e.g. to measure the mass of the neutrino) is still unclear.
4 Conclusions

We have presented a brief overview of the status and prospects of CMB polarization research. The scientific potential of investigating polarization cannot be underestimated: we can obtain crucial information on such topics as the physics of reionization, the energy scale of inflation, we can get much better constraints on cosmological parameters that are currently affected by severe degeneracies and even measure accurately the mass of the neutrino. The field is already in a phase of hectic activity, data of increasing quality are being released and many new missions devised. It is likely that if B modes exist and their level is not surprisingly low, they will be detected from a sub orbital effort within the next few years. However, in order to fully exploit the information in CMB polarization we will have to wait for a new generation satellite, that could hardly be in operation before the 2020s. The long road to this mission will be paved by the experiments under development.

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20