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PRECISE MEASUREMENT OF CMB POLARISATION FROM DOME-C: THE BRAIN AND CLOVER EXPERIMENTS

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Abstract. The characterisation of CMB polarisation is one of the next challenges in observational cosmology. This is especially true for the so-called B-modes that are at least 3 orders of magnitude lower than CMB temperature fluctuations. A precise measurement of the angular power spectrum of these B-modes will give important constraints on inflation parameters. We describe two complementary experiments, BRAIN and CLOVER, dedicated to CMB polarisation measurement. These experiments are proposed to be installed in Dome-C, Antarctica, to take advantage of the extreme dryness of the atmosphere and to allow long integration time.

1 Introduction

What is now known as the standard cosmological model (or concordance model) predicts the existence of primordial gravitational waves, generated during an explosive period of expansion known as inflation. This prediction remains yet to be tested and is the motivation for our proposed experiments at Dome C: to measure the so-called B-modes of the CMB polarization which are a signature of primordial gravity waves. The detection of gravity waves from inflation would not only be a major discovery for cosmology, but also for all of fundamental Physics. It would satisfy one of the primary objectives of modern Physics to detect these waves predicted by Einstein's General Relativity. It would furthermore be an indication of the quantum nature of gravity, for the excitation mechanism of inflation is inherently semi-classical (usually reserved otherwise for quantum fields). Finally, these B-modes would offer direct access to physics at energies inaccessible in laboratories and probably related to grand unification. For example, the amplitude of the B-mode would immediately give us the energy scale of inflation and hence the characteristic energy scale of unification physics (Knox, 2002).

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2 Observing the CMB polarisation

The exciting physics targeted by the B-modes requires improvements of up to two orders of magnitude in sensitivity with respect to the future ESA Planck mission (2007) that will map accurately intensity fluctuations and E polarisation of the CMB (Bouchet et al. 2003). This leads to the need for a CMB polarization measurement at large angular scale limited only by astrophysical limits. Obtaining such sensitivity represents an unequaled experimental challenge. Bolometers deliver the best detector performance, and those being built for the Planck mission will operate at the photon noise limit. The only way to improve sensitivity is by increasing the number of detectors. It is not, however, only a question of pure detector sensitivity: it is equally necessary to obtain exquisite control of all systematic errors (instrumental parasitic effects) to an unparalleled level. The final way to achieve that is by comparing results from independent experiments with orthogonal techniques as already happened for CMB anisotropy (Spergel et al. 2003).

Since the measurement is so difficult, independent orthogonal experiments are needed together with the very best astronomical site on Earth which is certainly Dome-C in Antarctica (proceedings of "Dome C Astronomy/Astrophysics Meeting", 2004). This site has huge advantages over other astronomical site, especially for CMB observations: high atmospheric transmission, low water vapor, stability of the atmosphere (polar vortex), sun always low in elevation. Moreover, these exceptional conditions are available very frequently allowing for very long integration time. Note that a variety of experiments have already been or will soon be operated from Antarctica: Boomerang, ACBAR, DASI, QuaD, BICEP.

We propose such strategy with the BRAIN/CLOVER program consisting in two complementary experiments with different instrumental approach.

3 The BRAIN experiment: a new instrumental concept

Although originally developed to increase angular resolution, aperture synthesis offers several advantages over direct imaging for observations of the CMB anisotropies, which include: (i) An intrinsically differential measurement, since one directly obtains the Fourier modes of the sky distribution (this is particularly advantageous for removing atmospheric signals). (ii) The unique sky tracking of the complete set of N antennas of the array allows the astrophysical signal to be separated from other sources or spurious signals (e.g., ground pick-up, etc). (iii) A direct polarization measurement as output of the correlator, instead of a determination based on the difference of two total power measurements.

These advantages together with the intrinsic sensitivity of bolometers are strong motivation for the development of a combined system. BRAIN is a prototype of bolometric interferometry which is being developed in our international consortium. It will have 2×2 input horns or 6 baselines. One baseline consists of a pair of corrugated feed-horns, working at 150 GHz, spaced by few wavelengths. The horns are directly observing the sky, without telescope, to reduce the sidelobe

level. They are cooled to 4K by a pulse tube system working continually and avoiding the use of liquid helium. At the output of each horn, the 2 polarisations are separated thanks to an Ortho-Mode Transducer. They are then phase-shifted at different frequencies. All 8 E-M signals from the 4 horns enter a Butler combiner that feeds 8 bolometers cooled to 300mK thanks to a ^3He fridge. A lock-in detection is used to recover the scientific signal contained at the beating frequencies of each phase-shifters and corresponding to the Fourier transform of one Stokes parameter on the field of view at a spatial frequency given by the length of the considered baseline. A simple model of the detection chain is shown figure 1.

It can be shown that such instrument has the same sensitivity of a bolometric imager with the same number of detector, with the additional immunity to systematic effects. It also allows a measure of all 4 Stokes parameters simultaneously with a simpler data processing since no map-making process is needed to recover the spatial power spectrum.

This instrument is proposed to be installed in Dome-C during the Antarctic summer 2005-06. It will be followed by a BRAIN version 2 with 3 bands (90, 150, 220GHz) each with 256 horns to look for B-modes (fig. 1). This complete instrument could be ready for operation in 2008 with a major contribution from French and Italian teams.

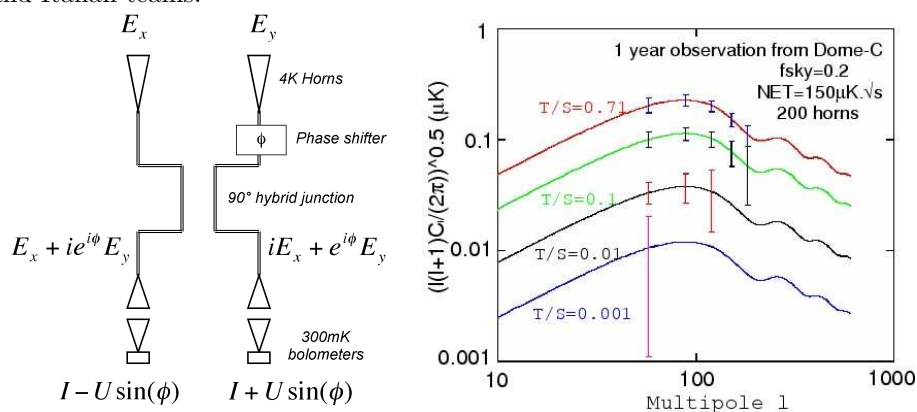


Fig. 1. Left: Principle of polarisation detection with BRAIN (we assumed $V=0$). Right: Expected errors from BRAIN V2 experiment on the B-mode power spectrum.

4 The CLOVER experiment

CLOVER is a bolometric imager aimed at mapping the primordial B-modes together with the lensed E-modes converted into B-modes. These lensed B-modes can lead to complementary cosmological information, such as neutrino masses. The CLOVER experiment uses 4 telescopes at 90 deg of the cryostat that image the same part of the sky on 4 arrays of 64 horns. Each detection chain is based on a pseudo-correlator scheme (fig. 2). It uses similar microwave components as BRAIN and allows to obtain for each pixel a EM signal that is proportional to

one of the Stokes parameter Q or U. The EM signal is furthermore converted into an electrical current with a finline structure. Each 4 currents coming from the same pixel on the sky are added and dissipated in a matched resistance on a small TES bolometer. This strategy allows to increase the signal-to-noise ratio with a relatively small number of detectors. The final CLOVER instrument will map the sky in 3 bands (90, 150, 220GHz) each with 4 telescopes and 64 TES. The complete instrument should be ready for operation in 2008.

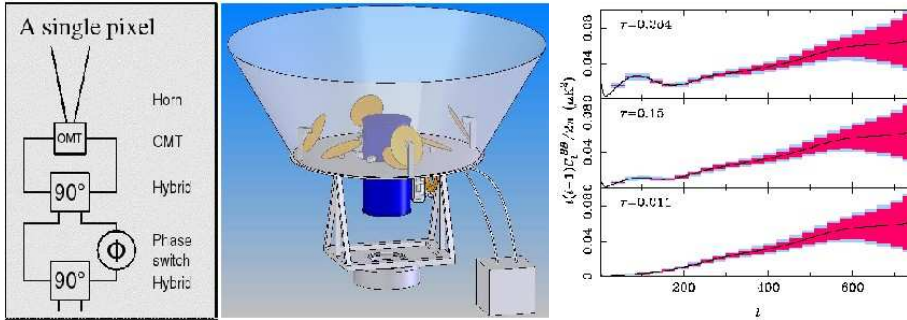


Fig. 2. Left: Principle of the detection chain of CLOVER (pseudo-correlator scheme). Middle: CAD view of one CLOVER channel with its 4 telescopes. Right: Expected errors from CLOVER on the B-mode power spectrum with different tensor-to-scalar ratio r .

5 Conclusion

The BRAIN-CLOVER program is aimed to find the CMB B-modes polarization from Dome-C, Antarctica, in the 2008 horizon. It is based on two orthogonal but complementary experiments that will also give important results on polarised foregrounds. This program is a first phase to develop a dedicated Post-Planck satellite to be launched around 2015-2020.

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