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THE BRAIN PROJECT:LOOKING FOR B-MODE FROM DOME-C

Cressiot C.[1], Piat M.[1], Kaplan J.[1], Bréelle E.[1], Dufour C.[1], Rosset, C.[2], Masi S.[3], Polenta, G.[3], Peterzen, S.[3,4,5] and the BRAIN collaboration[6]

Abstract. The detection and characterisation of Cosmic Microwave Background B-mode polarization is one of the next challenges in observational cosmology. This primordial polarization mode is only due to tensor perturbations of the metric produced by primordial gravitational waves, which could have been generated during the inflation epoch. With a signal of less than $0.1\mu K$, B-mode measurement requires very sensitive experiments and also an extremely good control of instrumental effects. In this paper we present the BRAIN experiment, a bolometric interferometer devoted to B-mode detection. This new detection architecture allows to directly measure the Fourier modes of the Stokes parameters. High sensitivity is obtained by using low temperature bolometers while systematic effects are reduced by using the interferometric technique.

1 Introduction

Cosmic Microwave Background polarization offers a unique opportunity to study the physics of the early Universe. Starting from unpolarized incoming radiation with local quadrupole anisotropy, Thomson scattering will produce linear polarization of the outcoming photons. In analogy with electric and magnetic fields, the polarization is divided in a curl-free component (E-mode) and a curl component (B-mode) (Kamionkowski et al., 1997; Zaldarriaga & Seljak 1998). Scalar perturbations in the early Universe can produce only E-mode polarization, while tensor perturbations will produce both E-mode and B-mode (Hu 2002). In the standard cosmological scenario, primordial gravitational wave background produced during inflation is the source of a B-mode polarization component. The amplitude of the resulting signal depends on the energy scale at which inflation occurs and could be of the order of $0.1\mu K$ (Turner & White 1996) with a typical angular scale of 2^o. B-mode polarization is one of the most important observable for both Cosmology and Fundamental Physics, probing the physics at Grand Unification Theory energy scale (10^{16} GeV), see e.g. (Hu 2002; Smith et al 2004). The small amplitude of B-mode make their detection a challenge for experimentalists.
The Brain project is dedicated to the detection and characterisation of B-mode from Dome-C in Antarctica. As a first step, to test the site and the logistics, we have installed what we call "the pathfinder" at Dome-C in January 2006. The BRAIN instrument will use a new kind of detection architecture based on bolometric interferometry. A first version will be installed at Dome-C in 2008 and will be improved through to 2010 when we expect the full instrument to be realized.

2 The Pathfinder: testing the site of Dome-C

French-Italian Concordia station in Antarctica has been choosen for its expected very low and stable humidity leading to a small atmospheric emission at far infrared wavelengths. This site also allows scanning strategies

[1] APC, Collège de France, 11 Place Marcellin Berthelot, 75231 Paris Cedex 05, France
[2] LAL, Université Paris-Sud 11, Batiment 200, 91898 Orsay Cedex, France
[3] Dipartimento di Fisica, Universit di Roma "La Sapienza", Roma, Italy
[4] ISTARS, Pagosa Spings, CO, USA
[5] Agenzia Spaziale Italiana, Roma, Italy
[6] with also CESR Toulouse (France), LISIF Paris (France), CSNSM Orsay (France), University of Wales Cardiff (UK) and Universita di Milano "Bicocca" (Italy)

with long integration time on small patches on the sky. The only drawback of this site is the extreme climatic conditions that make human activity very difficult.
The main goal of the pathfinder experiment is therefore 3-fold: (i) To characterize the atmosphere emission of Dome-C at 145 GHz both in intensity and polarization, (ii) to test the logistics of Dome-C and data transmission to Europe and (iii) to validate that the overall system is adapted for autonomous operations during Antarctic Winter.

2.1 Instrument description

The instrument consists of a dry cryostat with 2 thermal stages: the first one is a Sumitomo pulse tube cryocooler which has a limit temperature between 2 and 4 K depending on heat load. The second stage is a $^4He/^3He$ fridge able to cool the bolometers down to 0.3K. Two 45^o off-axis mirrors collect the radiation into the cryostat through a 8.5mm thick UHMW polypropylene window. The two optical chains are similar to Archeops 145 GHz channels. One of the bolometer comes from Boomerang while the other one has been made by University of Wales in Cardiff. One of the two optical chains has a polarizer and a rotating quarter-wave plate which converts circular to linear polarization (and viceversa). It can be shown that the signal detected by the bolometer is:

$$S = \frac{1}{2}\left[I + Q\frac{1+\cos(4\omega t)}{2} + U\frac{\sin(4\omega t)}{2} + V\sin(2\omega t)\right] \tag{2.1}$$

where I, Q, U, V are the Stokes parameters and ω is the rotating speed of the quarter-wave plate.
The circular polarization signal is therefore modulated at $2\times\omega$ and the linear polarization signal at $4\times\omega$, allowing us to extract the four Stokes parameters. Circular polarization from the atmosphere is expected due to Zeeman spliting of oxygen lines (Hahany & Rosenkranz, 2003). Mirrors can also move in elevation, and the whole instrument can rotate in azimuth, allowing different possibilities for both signal modulation and pointing solutions. This is especially useful to extract information on the total intensity of the atmosphere as well as to observe selected regions of the sky, such as Galactic plane and Magellanic Clouds.

2.2 Results from the first campaign

The first BRAIN antarctic campaign took place in January 2006. Most of the available time on site was used to setup the shelter to host indoor instrumentation such as compressor unit of the cryocooler, computers and data acquisition system. The shelter was placed 300 m from the main station to avoid the perturbations from the warm buildings. We installed on the roof the Inmarsat antenna for telemetry system as well as wi-fi antenna for

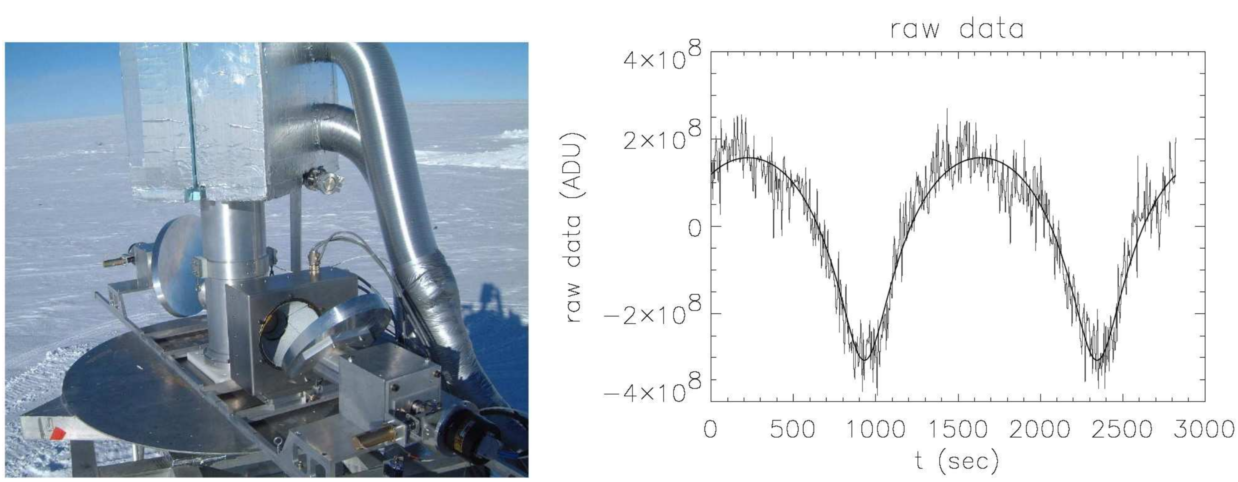

Fig. 1. *left*: Photography of the pathfinder experiment installed in Dome-C.; *right*: Raw data acquired during elevation scans and secant law prediction for atmospheric emission.

communication with the station. The cryostat has been run succesfully for 3 days, and we were able to run the

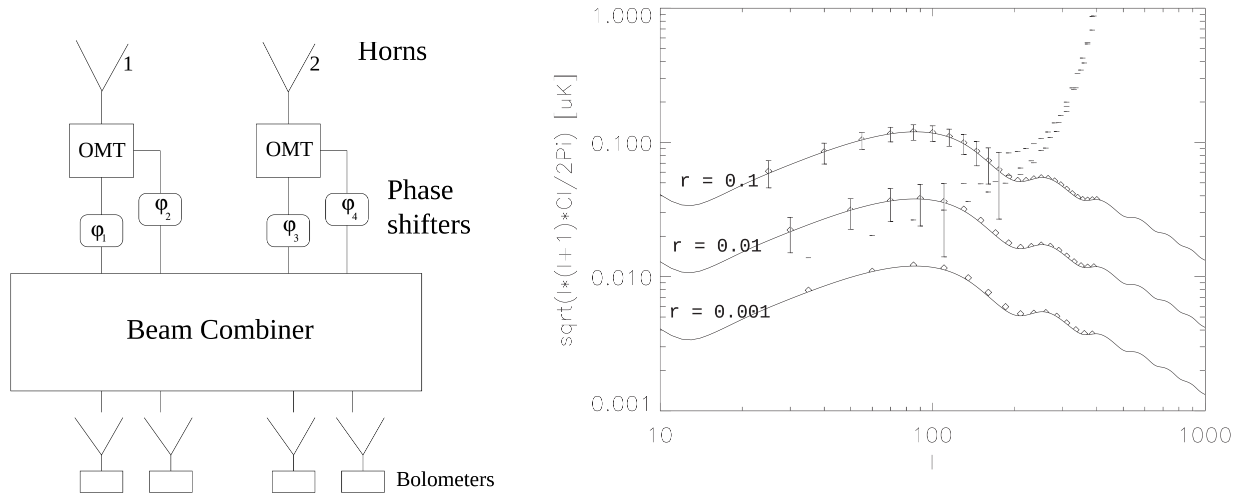

Fig. 2. *left*: Description of one baseline bolometric interferometry showing the different subsystems; *right*: Expected sensibility of the full BRAIN experiment on B-mode power spectrum for different tensor to scalar ratios r. We have assumed a one year observation on sky coverage of 1% and a typical bolometer sensitivity of $150\mu K.s^{0.5}$.

fridge and cool the detectors down to 370 mK. After a few test to validate the status of the whole instrument, we began observations of the atmospheric emission. Unfortunately, the available time for observation was shorter than expected and we had time only for a few elevation scans and one sky dip. The acquired data fit very well the secant law as expected for atmospherical emission, but measurements repeated at different azimuths and during different days would be needed to obtain a statistically significant estimation of the transparency of the atmosphere at 145GHz (Polenta et al., 2006). This will be the program for the forthcoming season.

3 BRAIN

BRAIN (Background RAdiation INterferometer) is a bolometric interferometer dedicated to the studies of the CMB polarization.

3.1 Instrument description

BRAIN will be composed of 16×16 horns array cooled at 4K. Each pair of horns is what we call hereafter a "baseline". For simplicity, we describe only one baseline, but the principle could be generalised.
The radiation entering the two horns is divided in two perpendicular polarizations by the Ortho-Mode Transducer (O.M.T.). Each electromagnetic signal is then phase shifted at a given speed. The beam combiner delivers a signal that is a complex linear combination of all inputs. The bolometers measure the intensity of these outputs. We can show that each bolometer measures the same signal with the power $\mathcal{P}_b$ given by:

$$\begin{aligned}\mathcal{P}_b = \frac{1}{4}\Big\{ & 2I + U[\cos(\varphi_1-\varphi_2)+\cos(\varphi_3-\varphi_4)] + V[\sin(\varphi_1-\varphi_2)+\sin(\varphi_3-\varphi_4)] \\ & + |\mathcal{V}_Q|[\cos(\phi_Q-\varphi_1+\varphi_3)-\cos(\phi_Q-\varphi_2+\varphi_4)] \\ & + |\mathcal{V}_I[\cos(\phi_I-\varphi_1+\varphi_3)+\cos(\phi_I-\varphi_2+\varphi_4)] \\ & + |\mathcal{V}_U[\cos(\varphi_2-\varphi_3-\phi_U)+\cos(\varphi_1-\varphi_4-\phi_U)] \\ & + |\mathcal{V}_V|[\sin(\phi_V-\varphi_2+\varphi_3)-\sin(\phi_V-\varphi_1+\varphi_4)]\Big\} \qquad (3.1)\end{aligned}$$

Where φ_i are the phase shifts and $\mathcal{V}_X = |\mathcal{V}_X|e^{i\phi_X}$ is the visibility of the Stokes parameter X. Varying the different phase shifts, we can recover all the visibilities. These visibilities are directly related to E and B modes on the sky. For a wide beam, the square modulus of visibility in U is the B-mode power spectrum. For more realistic beams, there is a leakage from E to B modes that can be corrected during data processing (Renaux, 2004).

3.2 Systematic effects

Interferometry is useful to reduce the leakage of I Stokes parameter in Q and U. Timbie (Timbie, 2006) has shown that, with interferometry, there is no leakage, from temperature to E and B modes. This is due to the fact that interferometry is a differential measurement. However, there is still a cross polarisation induced by the method, that transforms the differential ΔT in Q or U Stokes parameters. These effects (and others) are now under study.

3.3 Performances

The sensitivity of such interferometer can be determined by averaging the cross correlation of parallel baselines probing the same angular scale. A bining of different baselines can also be applied to improve the sensitivity. We have demonstrated that bolometric interferometry has the same sensitivity as an imager with a number of detector given by the number of baselines (Cressiot, 2006).
For the full BRAIN experiment with 16×16 horns, the accuracy of B-mode characterisation shows that a tensor to scalar ratio $r = 0.01$ could be accessible between $\ell \simeq 30$ and 150 (see figure 2).

4 Conclusions

The BRAIN project is dedicated to the observation of CMB polarization from Dome-C in Antarctica. The first step consists in testing the logistics and the site at 145GHz both in intensity and polarization with a 2 pixels bolometric instrument called the "pathfinder". This system has been first installed and tested in Dome-C in January 2006 and will be operated for Winter 2007. The second step of this project is the development of the BRAIN instrument, a bolometric interferometer dedicated to B-mode detection and characterization. Interferometry allows to measure directly E and B-modes with a very good sensitivity thanks to the use of very low temperature bolometers. We are still studying systematic effects but it seems that this system has also lower and different systematic effects than an imager. We are now building a demonstrator of this technics that will be the baseline for the first BRAIN version to be installed in Dome-C in 2008.

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