QUIET - MEASURING THE CMB POLARIZATION WITH COHERENT DETECTOR ARRAYS

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The footprint of inflation in the polarization pattern of the CMB is expected at more than an order of magnitude below the limits of current polarization measurements. Large receiver arrays are mandatory for achieving the required sensitivity. We describe here the approach of the Q/U Imaging ExperiemenT (QUIET) which will use coherent detector arrays. Pseudo-correlation receivers have been produced at 40 (90) GHz in small massproducible chip packages. Deployment of the first arrays with 19 (91) receivers is taking place in 2008 in the Atacama Desert in Chile and an expansion to \( \sim 1000 \) receivers is foreseen for the future. The two frequencies and the selection of observing regions with minimal foreground and good overlap with other upcoming experiments will enable the detection of tensor to scalar ratios \( r \sim 10^{-2} \).

1 Introduction

Measurements of the Cosmic Microwave Background Radiation helped significantly in establishing the current cosmological model\(^1\). The CMB temperature anisotropies have already been measured to a high precision, while only in recent years experiments achieved sensitivities to detect and measure the much smaller polarization anisotropies. The polarization pattern is divided into the E- and B-modes where the former derive from the primordial density fluctuations and the latter from primordial gravity waves and from the lensing of the E-modes by matter in the line-of-sight. The yet undetected B-mode signal from primordial gravity waves can offer unique insights into the inflationary period\(^2\). Its size is model-dependent, parametrized by the tensor-to-scalar ratio \( r = T/S \), but it is expected to be at least one order of magnitude smaller than the E-modes so that a significant increase in sensitivity is required of future experiments. Since current receivers are nearing fundamental limits this leap in sensitivity is only feasible with large receiver arrays.

2 Status of Measurements

Figure 1 shows the status of the E-mode measurements from which it becomes clear that much higher sensitivity is required for meaningful constraints of the cosmological model. The first CMB polarization measurements were all performed by coherent detectors (DASI, CBI, CAPMAP, WMAP) while by now also bolometric experiments have proven their polarization capabilities for the CMB measurements (Boomerang, QUAD) with significant detections. Since the bolometers offer high sensitivity together with the option of an easy scaling to large arrays they are

\(^{\text{on behalf of the QUIET collaboration quiet.uchicago.edu}}\)
considered the main path for future CMB polarization experiments. However, both coherent and bolometric systems are crucial in approaching the challenge of measuring the tiny B-mode signal, so that the results can independently be verified by methods with different systematics. The most recent CMB polarization results from ground-based coherent detectors came from the CAPMAP experiment. 12 W-band (90 GHz) and 4 Q-band (40 GHz) receivers were used on the Crawford Hill 7 m antenna in New Jersey. Data from ∼1660 hours of observing a 7.3 (9.2) square degree region around the NCP in W(Q)-band were processed in two independent pipelines. The final power spectra were evaluated from a selection of ∼950 hours with consistent results from both pipelines. A series of null tests ensured the absence of contamination from ground-signals or foregrounds. The measurement is competitive with the other ground-based efforts and extends the measurements to higher multipoles. The experiments to date have used at most a few 10s of receivers and therefore they were only able to provide upper limits for B-modes.

3 The Q/U Imaging ExperimenT (QUIET)

The developments for the low frequency receivers of the Planck space mission at the Jet Propulsion Laboratory (JPL) led to the integration of a pseudo-correlation receiver in a compact chip package, allowing for a mass production of coherent receiver arrays at low cost. The QUIET collaboration formed in 2003 around the groups involved in the CMB polarization experiments CAPMAP and CBI to take advantage of these receivers for measurements of the CMB polarization. By now it consists of experimental groups from 12 institutes (Max-Planck-Institut für Radioastronomie Bonn, Caltech, Columbia University, JPL, Kavli Institute for Cosmological Physics at the University of Chicago, Kavli Institute for Particle Astrophysics and Cosmology at the Stanford University, KEK, University of Manchester, University of Miami, University of Oslo, University of Oxford, Princeton University). Two prototype detector arrays are being built, one with 91 elements at 90 GHz and one with 19 elements at 40 GHz.

The scheme of the receiver together with a photo of the W-band (90 GHz) prototypes can be seen in figure. The incoming radiation is coupled via a feedhorn to an Orthomode Transducer (OMT) which then feeds the chip receiver with the left and right circularly polarized components. The feedhorns were produced as platelet arrays, using about 100 plates with different hole patterns which when bonded together form a corrugated horn array. The high bandwidth (20%)
OMTs were produced as septum-OMTs in split-block technique. Within the receiver chip package the radiation is amplified by Indium Phosphide (InP) High Electron Mobility Transistors (HEMTs) implemented as Monolithic Microwave Integrated Circuits (MMICs). In one of the legs the signal is phase switched at 4 kHz which is well above the 1/f knee of the amplifiers of $\sim 1$ kHz. After passing through a bandpass filter and another amplifier stage the signals from the two legs are combined in a 180 degree hybrid and coupled to diodes. The demodulated signal on those diodes corresponds to the Stokes parameter Q. A power splitter couples a part of the radiation via a 90 degree combiner to two additional diodes, where the demodulated signal corresponds to the Stokes parameter U. Measuring Q and U simultaneously, which allows valuable systematic checks, is unique to coherent technology.

The receivers together with the OMTs and horns are mounted in a cryostat which is cooled by a closed-cycle helium fridge to 20 K to ensure low noise from the amplifiers. The signal from the diodes is led out of the cryostat where it is digitized on a custom electronics board by 800 kHz ADCs and demodulated using a Field Programmable Gate Array (FPGA). The digital demodulation allows a flexible processing of the data stream, the monitoring of high-frequency noise and the creation of quadrature demodulation data sets for a check of systematics.

The averaged signal on the diodes gives a measure for the total power but is compromised by the 1/f noise of the amplifiers since no phase switching is applied. In order to retrieve clean total power information 10% of the receivers were modified for a differential total power measurement: The orthogonal polarizations from the signal of neighboured feeds are coupled via a Magic Tee to the chip packages so that the demodulated output on the Q diodes provides a measurement of the temperature difference measured between the two feeds. This addition is crucial for CMB TT and TE measurements and for the identification and removal of unpolarized foregrounds.

The cryostat together with the primary and secondary mirror of a new 1.4 m telescope is surrounded by a box covered with eccosorb to form an absorbing ground screen. The structure will be mounted on the CBI platform in the Atacama Desert in Chile (5080m) where the high altitude and the dry atmosphere provide excellent observing conditions with little atmospheric contamination.

The 40 GHz array is undergoing final tests and is scheduled to be shipped to Chile in June 2008. The 90 GHz array is still in production and planned to be finalized by the end of 2008. The work on the possible extension of the arrays to up to $\sim$1000 receivers is in progress.

4 Science reach

QUIET will focus its sensitivity on four selected patches with minimal foreground contamination, each 400 square degrees. The exact observing regions will be coordinated with other experiments with different frequencies (Polarbear, Clover, Ebex) in order to allow optimal foreground characterization and removal.
A first analysis pipeline using time-stream filtering for 1/f removal, optimal map-making and the Pseudo-$C_l$ method\textsuperscript{6} for the power spectrum estimation is being developed and already in use for the investigation of several systematics. The projected measurement errors for the E- and B-mode power spectra from this pipeline are shown in figure 3. The error bars for phase I (II) are derived using the expected sensitivity of a 50 (500) element W-band array observing for 10 (20) months at 50\% efficiency. In order to account for the sensitivity loss from foreground removal the Q-band sensitivity has not been used for these estimates.

In phase I the first peaks of the E-mode spectrum will be measured to unprecedented precision. Expanding the arrays will give access to the B-modes from gravitational waves. QUIET will be able to give a comparable precision on cosmological parameters other than $r$ as expected from the space mission Planck but provide deeper maps of small regions of the sky. While Planck will be able to measure a tensor-to-scalar ratio of $r = 0.05$ using the reionization signal at very low $l$ QUIET will target the maximum of the B-mode signal at $l = 100$ and be able to reach $r \sim 10^{-2}$.

5 Conclusion

The first coherent detector array at 40 GHz will start data taking in mid 2008. With a 90 GHz array following in the winter the sensitivity will allow measurements of the E-mode spectrum at an unprecedented precision. Expansions of the prototype arrays to up to 1000 detectors are foreseen and will provide the sensitivity to access the B-modes from primordial gravity waves down to levels of $r \sim 10^{-2}$.

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