The QUIET experiment

Bruce Winstein

Kavli Institute for Cosmological Physics, The University of Chicago

E-mail: bruce@kicp.uchicago.edu

Abstract. In this talk I will discuss the status of QUIET and prospects for the future. Our studies of the effects of possible sources of systematic uncertainty will be shown, in keeping with the emphasis of this meeting.

1. Introduction

QUIET is an international collaboration of 12 universities and laboratories with about 30 scientists on the project. The current team can be found on our public website: http://quiet.uchicago.edu. QUIET uses coherent polarimeters fabricated at JPL and observing from what was the CBI site in the Atacama desert in Chile. QUIET aims to address both the expected signal from gravitational lensing and the hypothesized signal from gravity waves generated at the time of inflation. Phase I is in operation and will include a 44 GHz receiver (now taking data) and a 90 GHz receiver (to be operational in March 2009). The Table below gives the parameters of the experiment and its receivers.

Table 1. Features of QUIET Phase I.

Angular Resolution	Q:28/W:12	Arc minutes
Frequency Coverage	44/90	GHz
Sky Coverage	4x400	Square Degrees
Multipole Coverage	60-450/60-1000	
Polarization Modulation	Phase Switching	
	PA and Dec angle Rotation, rapid scanning	
Types of Detectors	MMIC based	
Location	Atacama Desert	Ground
Instrument NEQ	70/60	$\mu K sqrt(s)$
Expected limit on r	0.15	no foregrounds
Status	Phase I Funded	

Figure 1 shows the institutional responsibilities for the receivers and telescope.

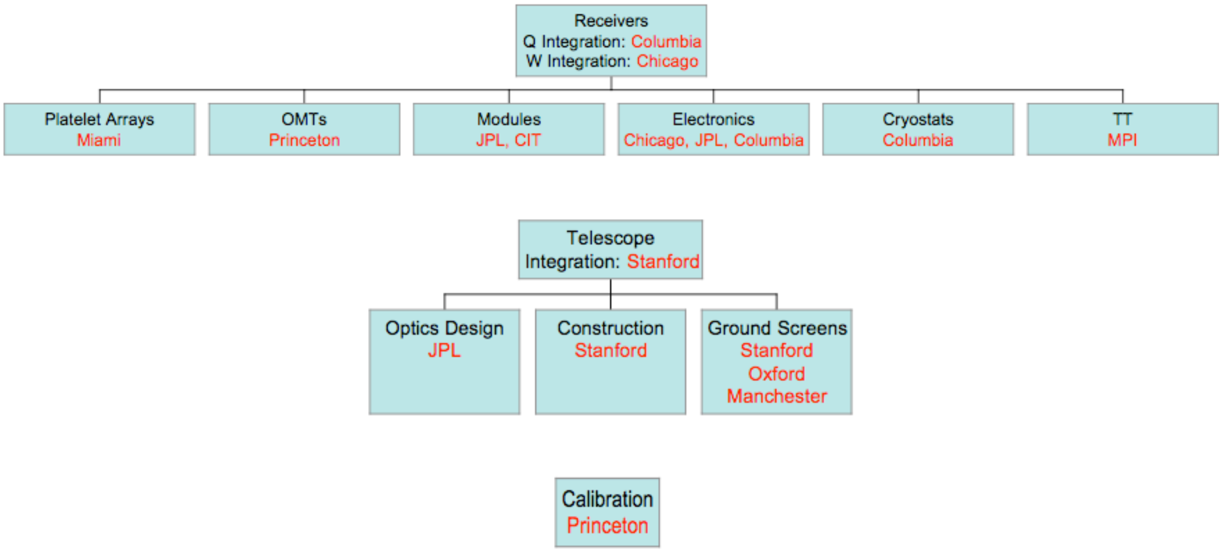

Figure 1. QUIET Institutional responsibilities for the receivers and telescope. Not shown are site management (Caltech), and software (which includes KEK and Oslo).

2. The Receivers

A photograph of one of the 90 GHz modules is shown in the Figure 2 . These modules provide two measurements (square-wave detection) of both Stokes Q and U. All detected signals are modulated at 4 KHz, well above the knee frequency of the MMIC amplifiers.

The signals are sampled at 800 GHz with 18 bit precision. The ADCs have onboard FPGAs which both blank out the phase transitions, demodulate the time streams to 100 Hz, and provide a Quadrature time stream (again at 100 Hz) which should contain no cosmological signal. Such rapid sampling also permits the study of noise sources up to 400 KHz.

The radiation first hits a platelet array of corrugated horns, shown in Figure 3. Next L/R OMTs prepare the signals for the modules themselves which are electrically connected to circuit boards which provide bias voltages and diode protection. These elements are all held at 20K; Flexible Printed Circuits carry the module signals and bias voltages to connectors mounted in the cryostat wall. These are followed by (warm) preamps and the ADCs.

The receivers are mounted on the side-fed Dragonian telescope, Figure 4 supported by a sled which is directly mounted to the CBI mount.

3. Laboratory Calibration/Characterization

The full receiver system is calibrated in the laboratory. We use a variation of the scheme developed for the CAPMAP experiment. Loads of 77K (N_2) and 87K (Ar) are passed rapidly over the array: this yields a gain and sensitivity. But a more accurate measure of the sensitivity comes from spinning a metal plate at 45 degrees to a load; this creates a polarized signal of order $100mK$ which can be seen to switch from Q to U, etc. From such measurements, the polarized gains and sensitivities are determined and are reproducible at the few percent level. A polarized offset (from the load) is removed by using multiple metals. Any possible gain saturation effects would compromise this measurement.

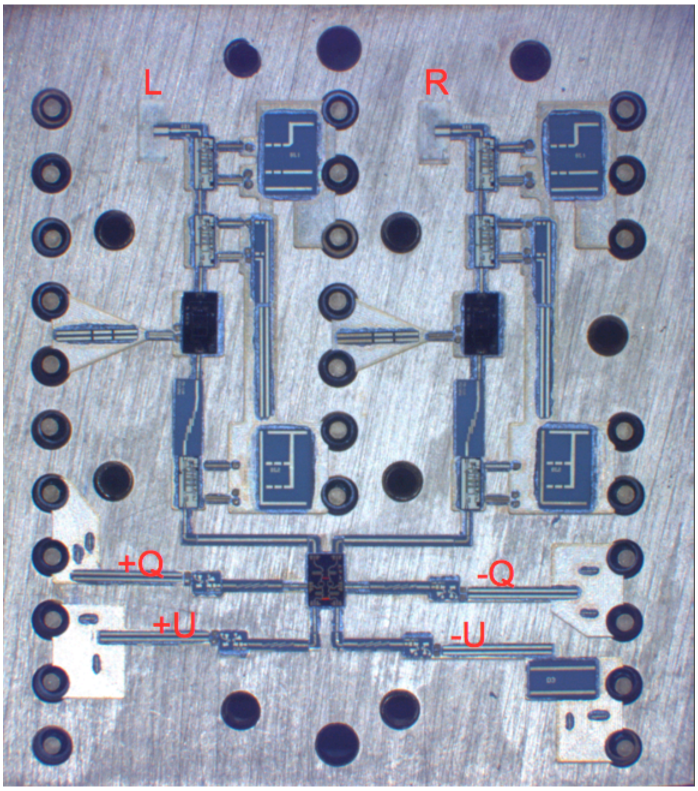

Figure 2. A QUIET W-band module (JPL). The dimensions are approximately 1” by 1.1”. The L and R inputs to the module are shown and the 4 detector diodes are indicated. In each leg one can see the low-noise amplifiers, phase switches, and filters.

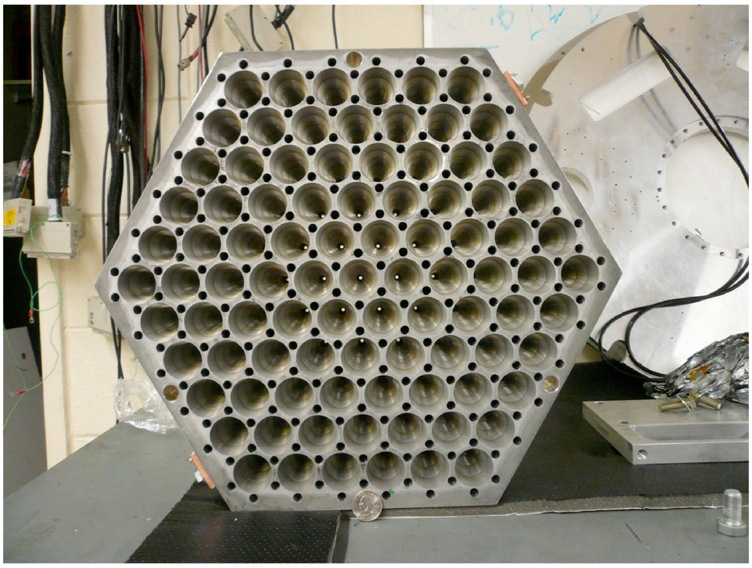

Figure 3. W-band platelet array.

Figure 4. The Q-band receiver mounted on the QUIET telescope (during integration).

4. Observing Strategy

Four patches have been selected for low expected foregrounds such that one of them is essentially always visible. This has been done in concert with POLARBEAR so that we will co-observe, bringing a much broader spectrum of frequencies to bear on the foreground problem. Our patches are approximately 400 degrees square.

5. Pipeline

A full pipeline has already been developed, one which begins with raw data and ends with power spectra. We have used this to study the systematics that we discuss later.

6. Sensitivity

The sensitivities of the current arrays are each about $60\mu K\sqrt{s}$. This is very close to the level that BICEP reached. The performance is below what we expected, by about a factor of 2. This degradation is mostly in the receiver temperature, likely some added noise when the amplifiers are packaged in their cases. This is under study with good prospects for a substantial improvement in our Phase II.

7. Systematic Studies

In this section we give a brief description of the possible systematic effects we have studied and what we have found. We find that for Phase I we have things under control while for Phase II, improvements in a few areas are needed. Most of these studies have been carried out by Akito Kusaka.

7.1. Cross-polar leakage

This optical effect arises from imperfections in the beam patterns on the sky. To evaluate these effects, we have convolved our beam pattern on the sky with a concordance TT spectrum and then simply taken the power spectra of $(T_x - T_y)/2$. Beams at different spots in the focal plane have been used. This study was done using our simulations for 2m optics and we are now using 1.4 m. But the designs are quite similar so those results ought to be quite good.

The result is that for all spots on the focal plane, the leaked B-mode power is well below what is expected from T/S = 0.01 for multipole values $l \leq 225$.

7.2. Polarization Angles

If one does not know the polarization axes of the detectors, that uncertainty will leak E power into B. We expect to be able to determine these at the level of 1 degree in the field, probably using the Moon. The leaked power is given by:

$$\langle BB \rangle \approx sin^2(2\theta)\langle EE \rangle \approx 4\theta^2\langle EE \rangle \tag{1}$$

so that even a few degrees (global) uncertainty will not kill an experiment. Furthermore, one can set the global angle so that the EB power vanishes:

$$\langle EB \rangle \approx sin(2\theta)\langle EE \rangle \approx 2\theta\langle EE \rangle. \tag{2}$$

Of course one then gives up sensitivity to a non-standard model effect: parity non-conservation.

7.3. E/B mixing: Geometry

Simulations here take into account the non-uniform coverage of our patches.

7.4. Filtering the Time Ordered Data

The filtering of the data does not generate any E-B mixing were the telescope scanning at constant velocity. However, we use data taken during telescope turnarounds so such an effect can be important. However, we find that the leakage induced from acceleration is only at the part-per-thousand level.

7.5. Instrumental I to Q/U leakage

This leakage can be measured both in the lab and in the field by seeing how much the demodulated polarization signals change with changing sky temperature. For QUIET Phase I this effect is at the 1% or less level; it comes primarily from an OMT-Module mismatch.

For the simulation, we have assumed leakages at the 1% level across the arrays but we have not tried to correct for them. Were the effects coherent, i.e. the same magnitude and sign for every module, we would have a large effect. But with the effects randomized over the arrays (as we certainly find in the lab), the leakage power is less than what would be expected for $T/S = 0.2$. Interestingly, the effects are smaller the larger the number of elements in the focal plane.

Even considering that we can correct for these effects, this is an area where improvement for Phase II is needed.

7.6. Gain Fluctuations

Gain fluctuations even of order 20%, from channel to channel, or on an hourly or daily time scale, are found to produce negligible B power. Even should there be a large systematic difference in gain between Q and U channels, that has effects but only for multipole values greater than about 300.

7.7. Pointing Errors

Systematic pointing errors in the scan of up to 10 arcmin were generated and found to give negligible excess B power.

8. Schedule

Phase I in operational now with the Q band receiver. It is likely that we will switch to W band in March, 2009. We have funding to operate until January 2010 by which time we expect to have enough data to make a very good measurement of the E-mode power spectrum at multiplole values below 1000 and to limit the B-mode power at the level of r=0.3. Phase II is expected to be a factor of 50 better; it will be proposed in late 2009.

9. Concerns

I will just make two observations here, concerning the seriousness with which the field is approaching the understanding of systematic uncertainty in upcoming experiments, let alone for an ultimate satellite experiment.

- It is interesting that while everyone has tables of (projected) systematic errors in their proposals, seldom does one find these in final results papers.
- More often than not, authors evaluate a systematic uncertainty as if it were the only contaminant. But in truth, one must put into one's simulations the suite of systematics and then see how they are determined, all together, and how they then limit sensitivity.

10. Acknowledgments

I would like to thank my colleagues on QUIET. I also acknowledge the KICP for supporting QUIET at Chicago. And I want to thank Gary Hinshaw and John Ruhl for organizing what turned out to be a very stimulating workshop.

11. Reference

[1] D. Barkats et al., *2005,ApJS,159, 1; e-Print: astro-ph/0503329*