QUIET: Goals and Status

B. Winstein
U of Chicago

- The Collaboration
- Technology
  - Current activities
- Telescopes and The Site
- The Science
- Fields/Foregrounds
- Conclusion
Collaboration

Experimental Groups Joining to Address CMB Polarization Using Coherent Devices

CAPMAP + CBI + ---
Chicago, JPL, Miami, Princeton
Caltech
Columbia, Stanford, Oxford, (MPI-Bonn)
“Polarimeter on a Chip”

T. Gaier et al., JPL
CAPMAP 90 GHz Polarimeter

~ $40K and 50 physicist-hours for checking, characterizing, etc

X-Y Polarizer

QUIET: Irvine Meeting, 3/24/06
W-band Module

- 18 GHz band width
- Simultaneous Q/U
- About 25 in hand
Q-band Modules

QUIET: Irvine Meeting, 3/24/06
QUIET L/R Correlator:
Simultaneous Q/U measurements

4kHz phase switching

$$|L \pm R|^2 = \left| \left( E_x + iE_y \right) \pm \left( E_x - iE_y \right) \right|^2 = 4E_x^2 + 4E_y^2$$

$$\left| (L \pm R) + i(L \mp R) \right|^2 = |L \mp iR|^2 = |L|^2 + |R|^2 + 2 \text{Im}(RL^*)$$

$$\text{Im}(RL^*) = \text{Im}\left( E_x + iE_y \right)^2 = 2E_x E_y = E_a^2 - E_b^2$$

QUIET: Irvine Meeting, 3/24/06
Q/U Radiometer on a chip
OMTs

P. Bannister, G. Nixon, S. Staggs
Princeton
(E. Wollack design)
OMT Characterization

\[
S_0 = \begin{pmatrix}
0 & 1/\sqrt{2} & 1/\sqrt{2} & 0 \\
1/\sqrt{2} & 0 & 0 & i/\sqrt{2} \\
1/\sqrt{2} & 0 & 0 & -i/\sqrt{2} \\
0 & i/\sqrt{2} & -i/\sqrt{2} & 0
\end{pmatrix}
\]
Platelet Arrays

J. Gundersen + students, Miami
7-element Prototype
Return Loss Measurements

Platelet Array + Interface Plate, 12/20/05

Return Loss (dB)

Frequency (GHz)

QUIET: Irvine Meeting, 3/24/06
91 Element W-band Array
Electronics & Warm Tests

D. Kapner, C. Bishoff, K. Vanderlinde, A. Brizius, M. Bogdan, BW

Chicago

M. Seiffert, J. Richards, S. Smith

JPL

QUIET: Irvine Meeting, 3/24/06
QUIET: Irvine Meeting, 3/24/06
High Speed Sampling
18 bits @ 800 kHz

- Monitors spurious high-frequency noise
- Digital blanking of phase transitions
- Permits Quadrature Samples
- Q/U measurement every 250µs
Time-Stream Noise Reduction with Differencing

-J. Richards

QUIET: Irvine Meeting, 3/24/06
QUIET Calibration/Optimization

\[ U_{\text{observed}} = (U_{\text{reflected}} + U_{\text{observed}}) \]
\[ = -\sqrt{4\pi\nu\rho\varepsilon_0 (\cos\beta - \sec\beta)}(T_{\text{plate}} - T_{\text{load}}) \]
\[ \approx 116 \text{ mK} \]

QUIET: Irvine Meeting, 3/24/06
QUIET Optimizer
Module Calibration & Sensitivity
(using QUIET Optimizer)

- 1.7 mKs$^{0.5}$ module sensitivity @ RT
- Expect 10% improvement with better blanking
- Expect x6 improvement operating cold -250 uKs$^{0.5}$
- Can measure relative Q/U phase to a few degrees in the lab
Cryostat

A. Miller*, L. Newberg
Columbia
*NSF Career grant for Q-band receiver
QUIET SCHEMATIC

QUIET: Irvine Meeting, 3/24/06
The First QUIET W-band Cryostat

Seth Hilbrand, Robert DuMoulin, Laura Newburgh, Amber Miller, Will Grainger
Telescopes & The Site

S. Church, K. Thomson: Stanford
C. Dickinson, T. Pearson, T. Readhead: CIT
B. Imbriale, M. Dragovan, E. Leitch: JPL
The Site for QUIET: CBI at 16,700 foot altitude in Chilean Andes

Atmospheric transmission=0.988
Extremely dry site: 1.38mm PWV
CBI infrastructure exists, ALMA soon to be installed

Operational Support:
SAINT

Ground-screen: Oxford
(M. Jones, A. Taylor)

QUIET: Irvine Meeting, 3/24/06
7m Bell Labs Telescope used by CAPMAP - 4’ beam at 90 GHz. Great for small scales, plan to move to Atacama Desert.
Side-Fed Dragonian geometry

Tim Thurston
# Beam Properties

<table>
<thead>
<tr>
<th>Frequency</th>
<th>HPBW</th>
<th>multipole</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 GHz</td>
<td>28 arc-min</td>
<td>390</td>
</tr>
<tr>
<td>90 GHz</td>
<td>12.6 arc-min</td>
<td>860</td>
</tr>
</tbody>
</table>

QUIET: Irvine Meeting, 3/24/06
QUIET Cross-polar leakage
H.K. Eriksen

Power spectra of \((T_x - T_y)/2\) [90 GHz, 2 meter telescope]

FWHM = 9.2'; beams are normalized to unity integral; offsets are given in inches

Power spectrum, \(C_l (l+1)/2\pi (\mu K^2)\)

\(T/S = 0.002\)
Site Affords Excellent Paralactic Angle Coverage
The Science
QUIET Produces Very Deep Polarization Maps

Stokes Q over a 400 square degree patch
Beam FWHM = 0.15 deg

Large scale W-band sensitivity: }  Phase I: 400 nK/deg$^2$
Phase II: 85 nK/deg$^2$  H.K. Eriksen

QUIET: Irvine Meeting, 3/24/06
Expectation for QUIET

Analysis:
JPL: K. Gorski
Chi: K. Smith
TT/TE with 10% of the Modules

D. Samtleben, K. Smith

1.4 m telescope

7m telescope

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Foregrounds
**WMAP Foreground Model**

P06 mask; Synchrotron + dust

\[
l(l + 1)C_l^{BBfg} / 2\pi = \left[ B_s (\nu / 65)^{2\beta_s} + B_d (\nu / 65)^{2\beta_d} \right] l^m
\]

Evaluate at \( l = 100 \):

<table>
<thead>
<tr>
<th>( \nu )</th>
<th>Sync</th>
<th>Dust</th>
<th>Total (( \mu K ))^2</th>
<th>BB T/S=0.18</th>
</tr>
</thead>
<tbody>
<tr>
<td>44 GHz</td>
<td>0.19</td>
<td>0.010</td>
<td>0.20</td>
<td>0.028</td>
</tr>
<tr>
<td>90 GHz</td>
<td>0.003</td>
<td>0.082</td>
<td>0.085</td>
<td>0.028</td>
</tr>
</tbody>
</table>
• QUIET will:
  – Coordinate to observe the same patch with an experiment having 150 GHz capability
  – Consider some channels at 30 GHz

<table>
<thead>
<tr>
<th>ν</th>
<th>Sync</th>
<th>Dust</th>
<th>Total (μK)^2</th>
<th>BB T/S=0.18</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 GHz</td>
<td>huge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44 GHz</td>
<td>0.19</td>
<td>.010</td>
<td>0.20</td>
<td>0.028</td>
</tr>
<tr>
<td>90 GHz</td>
<td>0.003</td>
<td>0.082</td>
<td>0.085</td>
<td>0.028</td>
</tr>
<tr>
<td>150 GHz</td>
<td></td>
<td>huge</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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QUIET Foregrounds

Two reasons for optimism

– Can get a good handle on foregrounds by even modestly splitting bands
  • (tunable) Band spread over radiometers
  \[
  \frac{d}{dv} C_{l}^{\text{sync}} (44) = -13\% / GHz
  \]
  \[
  \frac{d}{dv} C_{l}^{\text{dust}} (90) = +3\% / GHz
  \]

– P06 is 9.33 str, whereas QUIET-1 is just 0.5 str
  • Can choose the cleanest of patches on which to go deep
  • We chose 8 such patches prior to W-map: C. Lawrence
    – 6 survived P06
Schedule & Funding

If we’re funded, we’re ready to go!

Advice to Nigel …

From Friedrich Schiller:

“\textit{Aim for QUIET ..
but by balance..
not by stopping your other activities}”

QUIET: Irvine Meeting, 3/24/06
• Magnitude ~ -27 dB
• Primary effect is leakage of atmosphere 1/f into polarization channels
• Mandates removal of mean every scan (8 seconds)

Figure by Hedman; PIQUE data (2000)
QUIET: Irvine Meeting, 3/24/06
Electronics
Side-Fed Dragonian geometry
Expectation for QUIET

B-mode Physics

<table>
<thead>
<tr>
<th>Phase</th>
<th>Lensing Power</th>
<th>Lensing Significance</th>
<th>$\nu$ Mass</th>
<th>Min. Detectable T/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$4.5\sigma$</td>
<td>$7.2\sigma$</td>
<td>0.5 eV</td>
<td>(0.10)0.16</td>
</tr>
<tr>
<td>II</td>
<td>$\sim25\ \sigma$</td>
<td>$\sim30\ \sigma$</td>
<td>0.12 eV</td>
<td>(0.006)0.009</td>
</tr>
</tbody>
</table>

Comparable to future limits from double beta decay, close to mass scale expected from oscillations
Amplitude of gravity wave contribution, gets down to energy scales below $10^{16}$ GeV

Already in Phase I measuring interesting physics!

Features of QUIET
- Measures Q and U simultaneously in the same pixel
- Measures at large and small scales
- Complements frequency coverage of bolometer arrays, important for foreground discrimination
Astrophysical Foregrounds

Estimates by WMAP of the temperature RMS as a function of frequency (extrapolation from maps at different frequencies)

Level of polarization not well determined with measurements,

Best estimates for average fraction of intensity:

Synchrotron: 10-75%
Free-free: <10%
Dust: <10%
QUIET: Irvine Meeting, 3/24/06

150 GHz

40 GHz

90 GHz

(D^2 + U^2)^{1/2}

Add CMB

Note: CMB not on same Color Scale

Smooth

To 40'

Keith Vanderlinde

To Foreground Removal
Monte Carlo power spectrum:
CMB E-mode + ILC residual foregrounds

No CMB B-mode in this simulation; a tensor B-mode with T/S=0.1 is shown solely for scale

Green: 90+150 GHz
Blue: 40+90 GHz
Purple: 40+90+150 GHz

Kendrick Smith
3-agency Task Force (R. Weiss)

Predicted Future Experiment Sensitivities

Angular Scale

Satellite

Ground

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First Module in Our 20K Board