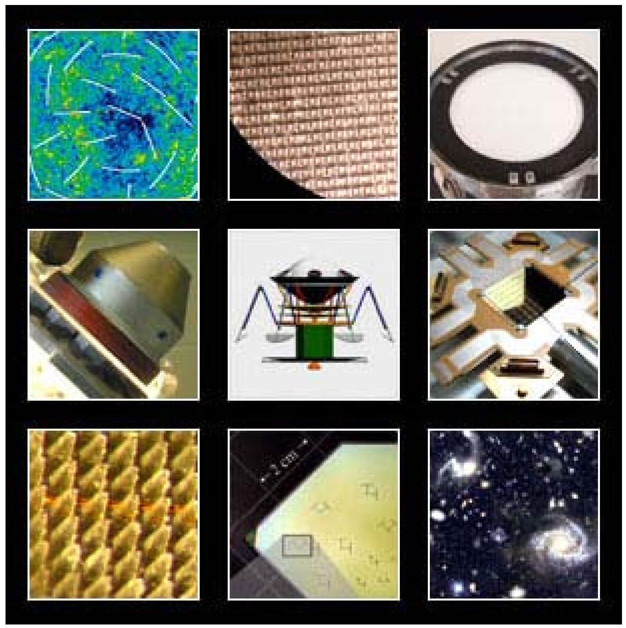
CMBPol Study - Systematic Error Workshop Summary



Gary Hinshaw

CMBPol Study - Technology Workshop

Boulder, CO, Aug 25-28 2008

Goals

Overall study (re systematics):

1. Identify the worrisome systematic effects, and propose a program for mitigating them.
2. Convince ourselves and decadal community that systematic effects are not going to limit CMBpol's scientific return.

Syserr workshop goals:

- Review & update the list of systematics from Weiss report.
- Document where things stand with systematics in current & pending experiments.
- Try to understand how these affect a more sensitive, all-sky measurement.
- Identify what still needs to happen to accomplish goal 2 above.

Proceedings will document the details. The systematic error section of the study report will be a high-level summary that will refer to the proceedings for details.

Effects: Syserr Table from Weiss Report

Parameter	Effect	Goal	Method
Cross-Polar Beam response	$E \rightarrow B$	< 0.003	Rotate Instrument, Wave Plate
Main lobe ellipticity (0.5° beam)	$dT \rightarrow B$	$< 10^{-4}$	Rotate Instrument, Wave Plate
Polarized sidelobes (response at Galaxy)	$dT \rightarrow B$	$< 10^{-6}$	Baffles/shielding/measure
Instrumental polarization	$dT \rightarrow B$	$< 10^{-4}$	Rotate Instrument, Wave Plate
Polarization angle	$E \rightarrow B$	$< 0.2°$	Measure
Relative pointing (of differenced samples)	$dT \rightarrow B$	$< 0.1''$	Dual-polarization pixels
Relative calibration	$dT \rightarrow B$	$< 10^{-5}$	Modulators
Relative calibration drift (scan synchronous)	$T \rightarrow B$	$< 10^{-9}$	Modulators
Lyot Stop Temperature (10% spill, scan synch.)	$dT_{opt} \rightarrow B$	$dT_{opt} < 30$ nK	Measure
Cold stage T drifts (scan synch.)	$dT_{CS} \rightarrow B$	$dT_{CS} < 1$ nK	Improve uniformity, measure

TABLE 6.1 *Performance goals for a CMB* **B**-*mode measurement. The first eight parameters describe instrumental effects that transform various sky signals into false* **B**-*mode signals; here we use* **T** *to indicate intensity,* **E** *to indicate the* **E**-*mode polarization signal, and* **dT** *to indicate CMB temperature anisotropies. The listed "Goal" is the level at which an individual instrumental effect will begin to cause a 10% contamination (in units of temperature) of an* r = *0.01* **B**-*mode signal in the most naïve experimental design. Clever scan strategies and partial correction of known levels of contamination can relax these requirements. See the text for more details.*

Workshop Organization - I

- Overview:
  - Co-organized by John Ruhl & gfh
  - Double Tree Hotel, Annapolis MD, July 28-30 2008.
    - Offsite from GSFC to by-pass security headaches.
  - Approx 40 attendees including reps from all major experiment groups, past and present, plus local students/postdocs.
  - Lots of discussion; padded schedule was only loosely adhered to.

- Talks:
  - Mon. am: intro session, study context, theory workshop report, general considerations.
  - Mon. pm: reports from experiments with analyzed data.
  - Tue. am: reports from experiments in progress/development.
  - Tue. pm: summaries of concepts for satellite missions.
  - Wed. am: analyses of requirements for satellite, eg. scan strategies, E/B mixing, beam effects.

Workshop Organization - II

- Program and talks available on-line at CMBPol study website:
  - Program: http://cmbpol.uchicago.edu/workshops/systematic2008/program.html
  - Talks: https://cmbpol.uchicago.edu/groups/cmbpol/wiki/a8c44/Systematics_Workshop_Presentations.html
  - Short papers based on talks will be published by IOP in online proceedings.
  - NOTE: papers due September; details to be circulated by e-mail.

- Workshop summary document:
  - Summary document to be written by John Ruhl & gfh.
  - Aided by 5 professional note takers, each assigned a topic:
    - Suzanne Staggs / Brian Keating — Calibration
    - Lyman Page — Beams
    - Al Kogut — Pointing
    - Charles Lawrence — Environmental
    - Peter Timbie — Other
  - Summary will feed into study report led by Stephan Meyer.

Effects/Categories: Updated Syserr Table

1. Beam issues		
	Crosspolar beam	E->B
	Main beam asymmetry (before differencing)	dT->B
	Sidelobes	dT->B
	etc	
2. Pointing issues		
	Polarization angle errors	E->B
	Pointing errors (on Q/U)	E->B
	Pointing errors before differencing	T->B
	etc	
3. Calibration issues (including gain, bandpass and freq response)		
	Relative calibration errors	dT->B
	Gain drift before differencing	T->B
	Band shape errors, including modulator effects	foregrounds->B
	etc	
4. Environmental stability issues		
	Optics and spillover T variations	dTopt -> B
	Scan modulated cold stage variations	dTcs -> B
	etc	
5. Other issues		
	Instrumental polarization	dT->B
	? (look for additions that don't fit in above categories)	

Experiment Talks - I

- Attendees were given a 6-page talk template ahead of time
  - Prepared by Amber Miller, Dave Chuss, John Ruhl, gfh
  - Requests certain detailed material (and avoids general science)
  - Example: an experiment summary table (shown below for WMAP)

Angular resolution (FWHM)	48, 37, 29, 20, 12	arcminutes
Frequency Coverage	23, 33, 41, 61, 94	GHz (K,Ka,Q,V,W)
Sky Coverage	41253 (full)	square degrees
Multipole Coverage	2 - ~200	(sensitivity-limited)
Polarization Modulation?	limited	(see later)
Types of Detectors	coherent (HEMT)	-
Location	L2	space
Instrument NEQ*	520,532,515,618,743	$\mu K\ s^{1/2}$
Current limit on *r***	<0.43, <0.20	(WMAP, WMAP+BAO+SN)
Status	9 years of operation	(funded)

Experiment Talks - II

- Experiments with analyzed data (in order of presentation):
  - Maxipol (Hanany)
  - Boomerang/03 (Jones)
  - WMAP (Hinshaw)
  - QUaD (Pryke)
  - BICEP (Keating)
  - CapMap (McMahon)
- Experiments in development:
  - Spider (Jones)
  - EBEX (Limon)
  - PolarBear (Lee)
  - QUIET (Winstein)
  - MBI (Tucker)
  - Poincare (Chuss)
  - ABS (Staggs)
  - SPTPol (McMahon)
- Satellite concepts:
  - EPIC (Lee/Hanany/Keating)
  - HEMT concept (Lawrence)
  - Feed farm concept (Page)
- The talks were very candid, informative, and discussion-provoking!

Distilled Beam Notes (LP)

- Five beam effects noted (after Shimon et al.) all comparisons of two polarized detector channels that are differenced to form P measurements
  1. Relative gain difference
  2. Differential FWHM (m=0)
  3. Differential pointing offset (m=1)
  4. Differential ellipticities (m=2)
  5. Angle between polarization axis and beam axis.
  – All real beam have some combination of these effects.

- Mitigating strategies
  – Place beam resolution higher than scientific scales of interest (expensive!)
  – Scan over a range of sky azimuth angles
  – Modulate polarization ahead of the beam forming optics, eg., with a half-wave plate (HWP) or variable-phase modulator (VPM).

- Deriving hardware requirements is computationally expensive (but not prohibitive).
  – End-to-end simulations can only be usefully carried out for a specific mission profile: optical coupling approach, polarization modulation, and scan strategy.
  – Has been carried out in detail for limited number of cases, eg. EPIC.

Distilled Pointing Notes (AK)

- Polarization angle
  - Uncertainty in the angle the detector polarization plane makes with the sky.
  - Dominant effect is to mix Q&U or E&B.
  - Current experiments report measurements of angle with uncertainties from 0.2-2 degrees.
  - Required knowledge to avoid aliasing E→B for r=0.01 is ~0.2 degrees.

- Differential pointing error
  - If two detector pairs with slightly offset pointing can alias ΔI→B.
  - Two experiments reported displacements of order 0.1 arcmin.
  - Polarized response is dipolar and can be separated from sky polarization with appropriate azimuth angle coverage.
  - Unlikely to be a serious concern.

- Random pointing errors
  - Experiments report random pointing errors from a few arcmin to a few arcsec.
  - Errors integrate down with time and form a random noise.
  - Mission with a star camera should have few arcsec pointing with negligible noise contribution.

Distilled Calibration Notes (ST/BK)

- Gain calibration
  - Nearly all current experiments have detectors sensitive to I which provide the primary calibration that is transferred to Q and U.
  - Nearly all are essentially tied back to WMAP degree scale intensity anisotropy, with some groups augmenting with planets in I.
  - Experiment might not measure I -- that would complicate calibration
    - Perhaps calibrate off of E-mode, from experiments that did have I and calibrated to WMAP (or Planck).
    - Onboard sources?
    - Most experiment talks included plans for measuring I.

- Other calibration notes
  - Relative gain of xpol vs ypol detectors is monitored by a variety of means in current experiments.
  - Detector time constant deconvolution could matter if not well measured.
  - Polarization angle knowledge requirements are about 0.2 deg for r=0.01 limit;
    - BICEP managed 0.7 degrees (with ground-based method difficult to copy in flight).

Distilled Environmental Notes (CL)

- Primary emphasis is on thermal stability.
  - WMAP experience: L2 is a wonderful place to be with regard to environmental stability (with passive cooling).
  - WMAP primary mirror modulates by 150 μK at the spin period (129 sec) due to diffracted solar radiation.
  - Solar proton storms heat primary by ~50 mK. Random phase, low duty cycle → not a problem.
- Other environmental concerns:
  - magnetic shielding with superconducting components
  - microphonics (thermally or capacitively coupled) in large focal planes
- Complex scans help separate environmental effects
- Balloon altitude has significant effect on calibration

Distilled “Other” Notes (PT)

- Effects noted
  - Instrumental polarization (IP) - effects in the instrument (not including beam effects) that convert $\Delta I \rightarrow B$.
  - Radiation belts and charging - didn't hear much about these!
  - Detector transfer functions - time-domain response.
  - Frequency band passes - can alias foreground (non-flat spectrum) $\Delta I \rightarrow B$ if not matched between polarized detector pairs.

- Some sources of instrumental polarization noted
  - Optics before rotating half-wave plate.
  - Knife-edge diffraction at hard stops.
  - Calibration mismatch between detector pairs.
  - Reflections in correlation polarimeter.

- Notes on frequency bandpass mismatch
  - Half-wave plate can systematically modulate frequency band-pass.
  - In limit of uniform azimuth coverage, constant bandpass mismatch can be separated from sky polarization. Scan strategy – spin vs. scan?

Status & Assessment

- Proceedings will document the talks more formally. Talk papers will be due in September, authors watch e-mail this week for details. Tex template is available on syserr web site now.

- The systematic error section of the study report will be a high-level summary that will refer to the proceedings for details. Ruhl & gfh are working on this.

Group consensus: current experiments have not been limited by systematic effects (or foregrounds) but rather by instrument noise.

There was no consensus on future, more sensitive experiments; specifically on the question:

Can we start a mission *today* that would reach r=0.01 with high confidence, without being limited by foregrounds or systematics?

The End

WMAP Polarization Modulation: *l*=3