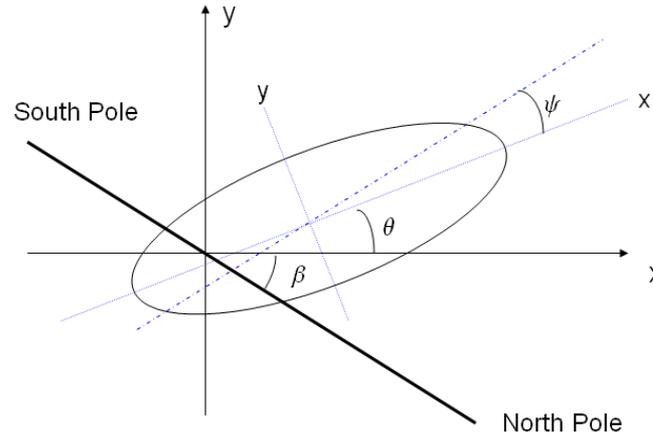


B-modes and Beams

Systematics and Parameter Estimation



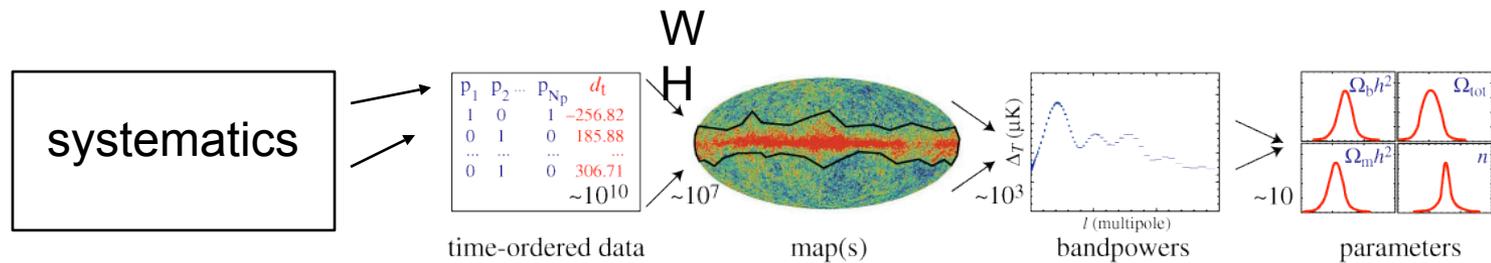
Brian Keating, Meir Shimon, Nathan Miller
Annapolis July 30, 2008



UCSD



From data Collection to Cosmological Parameters



C.f.: Julian's talk, cost of doing simulations. Frequency space is fast but probably inadequate for realistic processing simulations.

EPIC Systematics

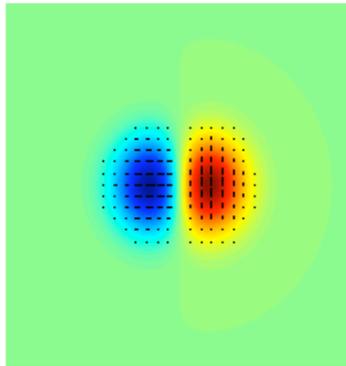
Mission Concept Study

Bock et al. -- *astro-ph 0805.4207*)

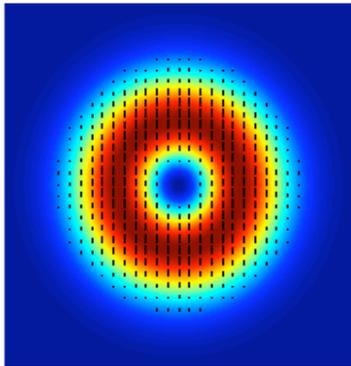
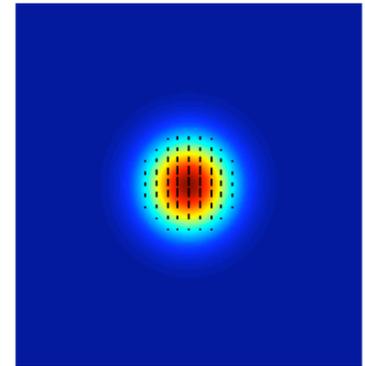
- Simulated both 5' "Low Cost" and 60' "CS" missions
- Largely based on Shimon, Keating, Ponthieu & Hivon 2008 (PRD v77).
- Found excellent agreement with map-domain approach (Ponthieu & Hivon)
- Have adapted EPIC pipeline for effects on secondary science, as well as primary B modes (Miller, Shimon, & Keating *astro-ph/0806.3096*)

Systematic effects in real space

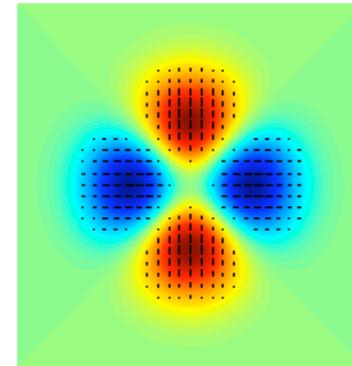
differential beam offset
(dipole IP effect)



differential gain
(monopole effect)



differential FWHM
(monopole effect)

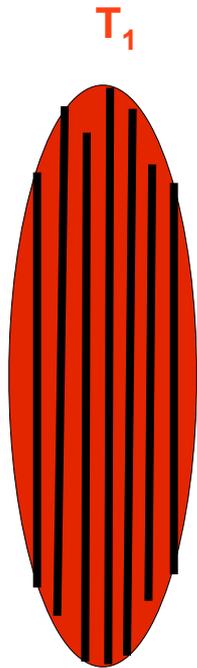


differential ellipticity
(quadrupole effect)

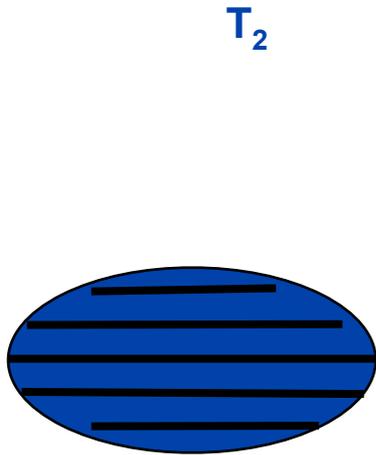


Irreducible

Irreducible Beam Systematic: Differential Ellipticity



-

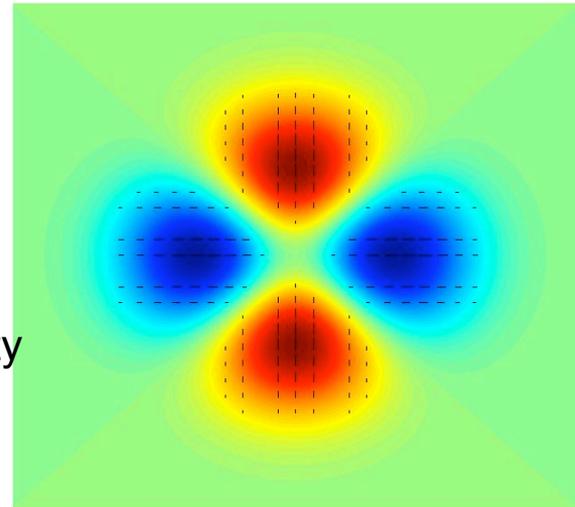


=

For an unpolarized point source

Text

Diff. ellipticity

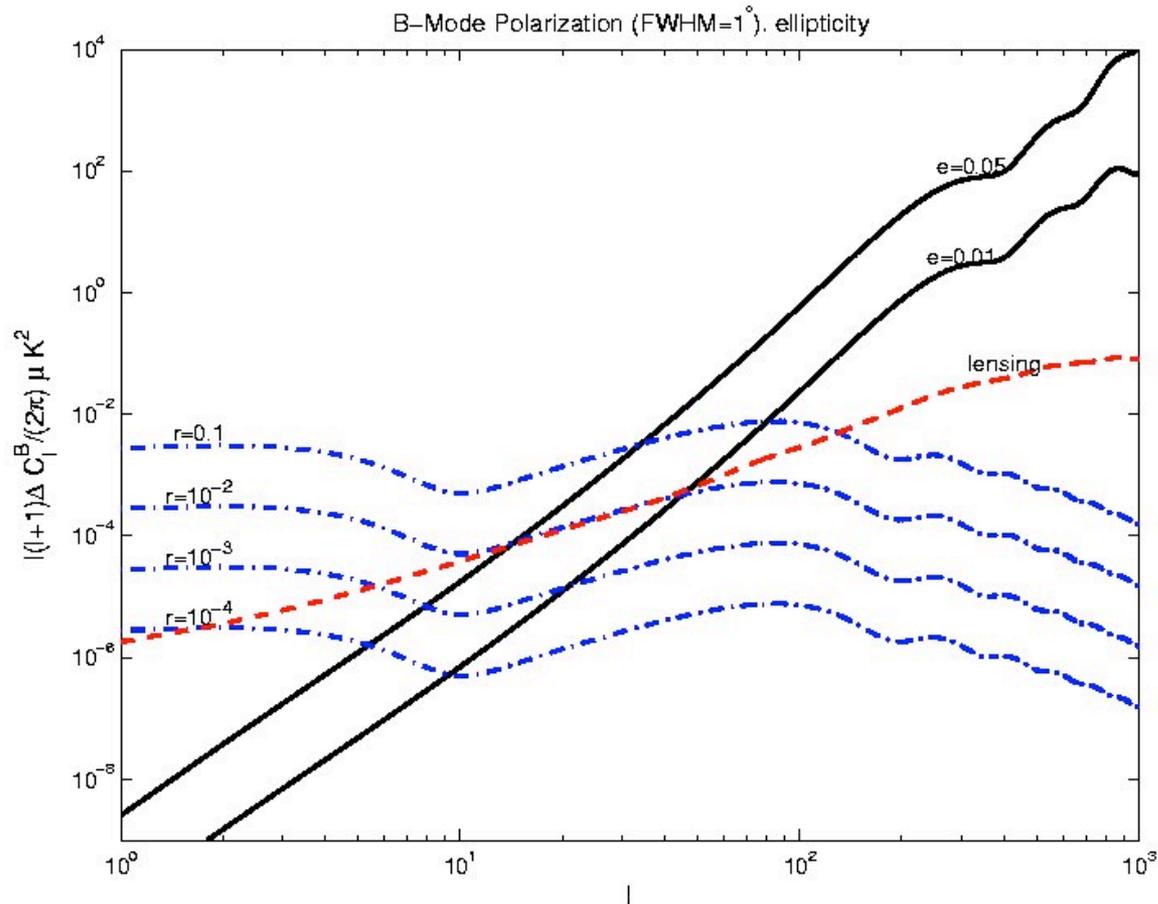
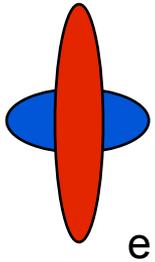


$$Q \propto \frac{\partial^2 T}{\partial x^2} - \frac{\partial^2 T}{\partial y^2}$$

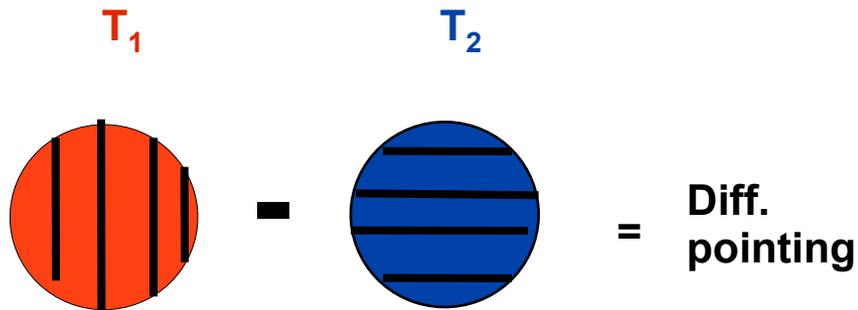
$$\left\langle \frac{\partial^2 T}{\partial \theta^2} \right\rangle \approx 0.1 \mu K / \text{arc min}^2$$

Intrinsic, on the sky

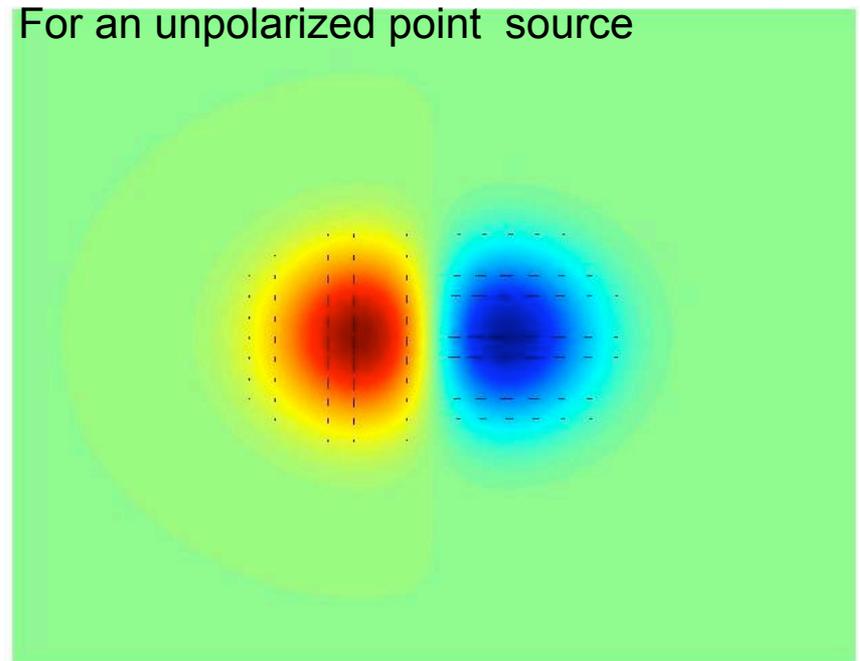
B-Mode Polarization (1°): Differential Ellipticity (Inst. Polarization)



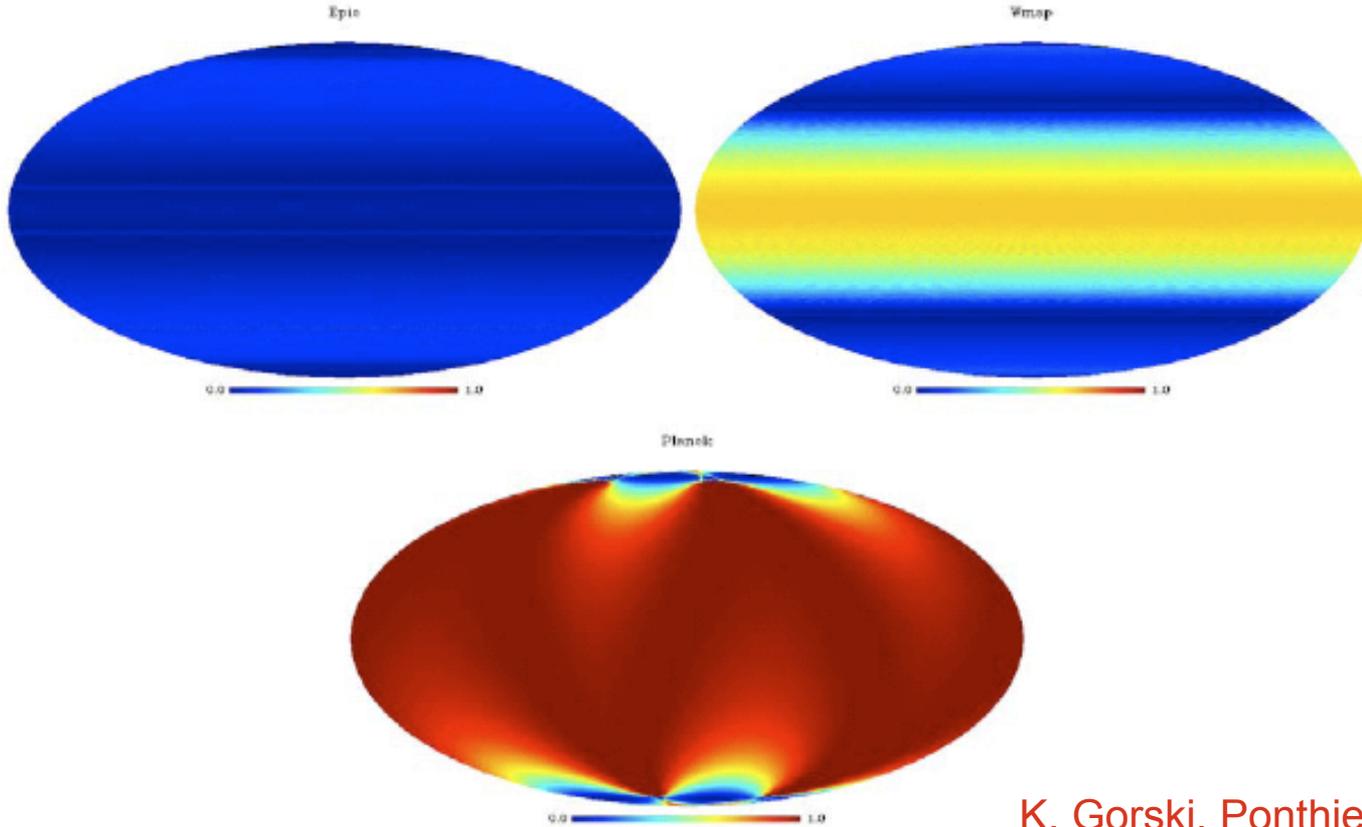
Reducible Beam Systematic Differential Pointing (Instrumental Polarization)



N.B. Both Differential ellipticity and pointing have an orientation angle which determines what fraction is converted to E or B.



Uniformity of Scan Strategy



K. Gorski, Ponthieu, Hivon

This is half of what we need to construct f-functions

Systematics: Basic CMBPol Goals

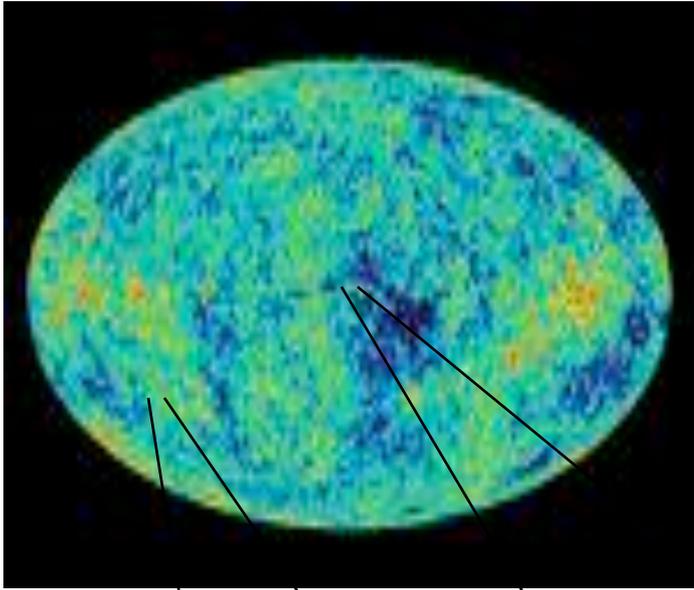
- We are working with Jamie Bock on the bolometer concept. This follows on our work which has led to detailed TOD and frequency domain systematics simulations - discussed in Shimon et al, Miller, Shimon, & Keating and the EPIC report Bock et al.
- Systematics susceptibility for several beam size missions; impact on all phases of science: primary B mode, foregrounds and secondary B modes
- We should incorporate feedback from first generation expts, like BICEP, QUAD.
- How well can strawman missions determine their beams?
- Systematics: beyond the main beam... thermal drifts, non-linearities, sidelobes etc, Time-domain effects, e.g. $1/f$ noise affecting low-ell modes.
- E/B mixing for cut sky maps...biases r?

Goals, continued

- Interplay of the scan strategy with systematics, work with scan team Gorski(?). Initially we assumed a uniform scanning strategy; it seems to apply to most of the observed sky patch (maybe except from the boundaries), it considerably simplifies the analysis.
- Optimization of scan to mitigate most pernicious systematics, rather than trying to reduce all. Even if the scanning strategy is non-ideal you can still 'idealize' it for the most part. You can do it by the brute-force approach - simply toss all data points at each pixel which contribute to the dipole, quadrupole and octupole *of the scan strategy*.
- We may find that designing an ideal scanning strategy is not the only or even most efficient way... Need to examine how we analyze the data, in particular: how we remove the non-ideal components.
- Modulators: influence on scan and systematics caused by modulators. We include the effect of HWP in our lensing work only at a cursory level. However, the HWP/other modulator, itself, introduces systematics.
- Investigate secondary science (CS effects, non-gaussianity, 4-point @ $l=2000$ etc)

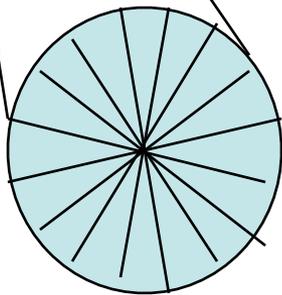
Post-scanning Idealization

- Differential gain, beamwidth couple to the quadrupole of the scanning strategy
- Differential pointing couples to the dipole thereof
- Experiments with reasonable scanning can benefit from throwing out the dipole and quadrupole from the data

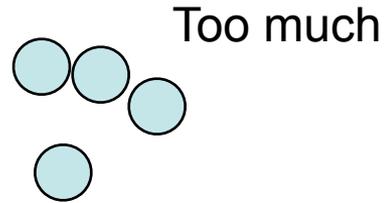
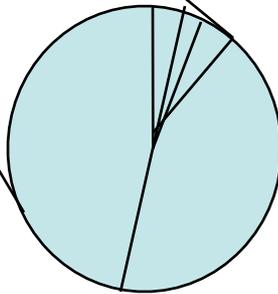


“Removing the dipole” refers to the multipoles of the scanning strategy, NOT to be confused with the “dipole” and “quadrupole” beam systematic effect.

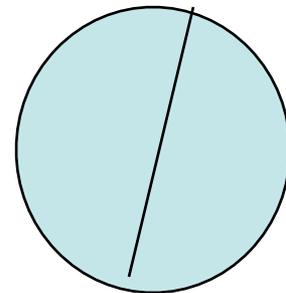
Removing the dipole of the scanning strategy eliminates the first order pointing error.



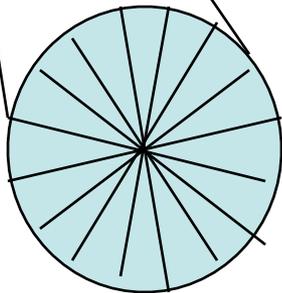
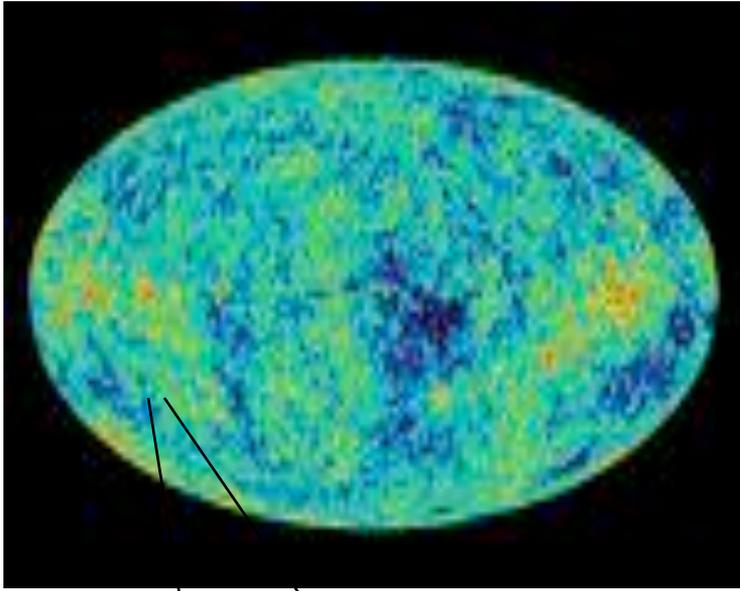
ideal



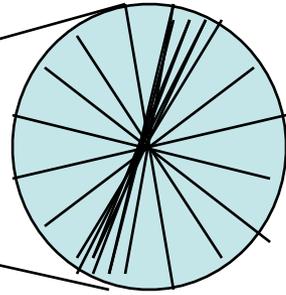
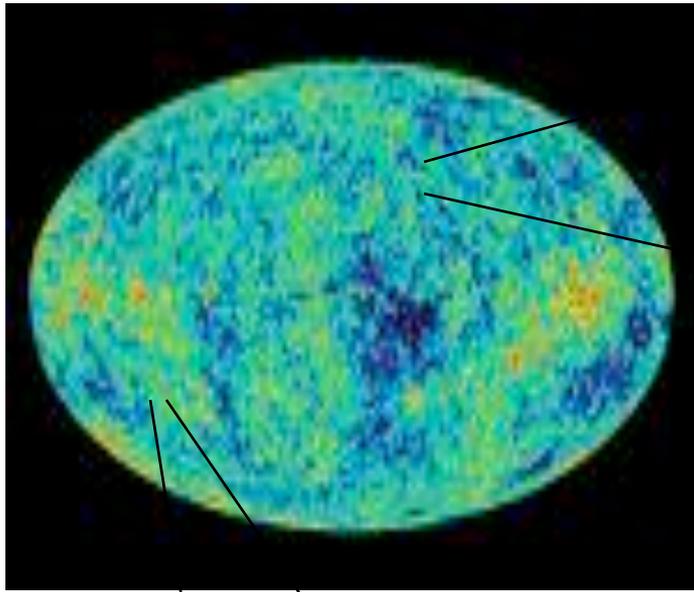
Removing the dipole



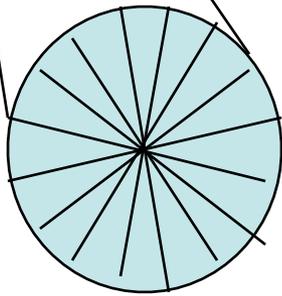
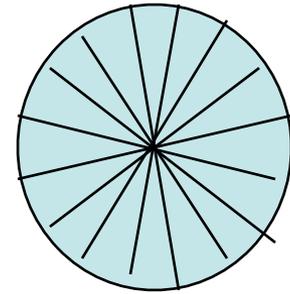
Scan Strategy Issues & Work TBD



ideal



Removing the
quadrupole

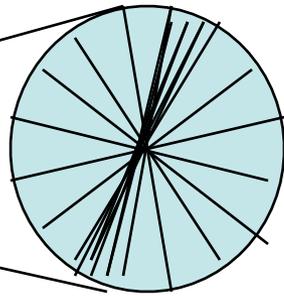
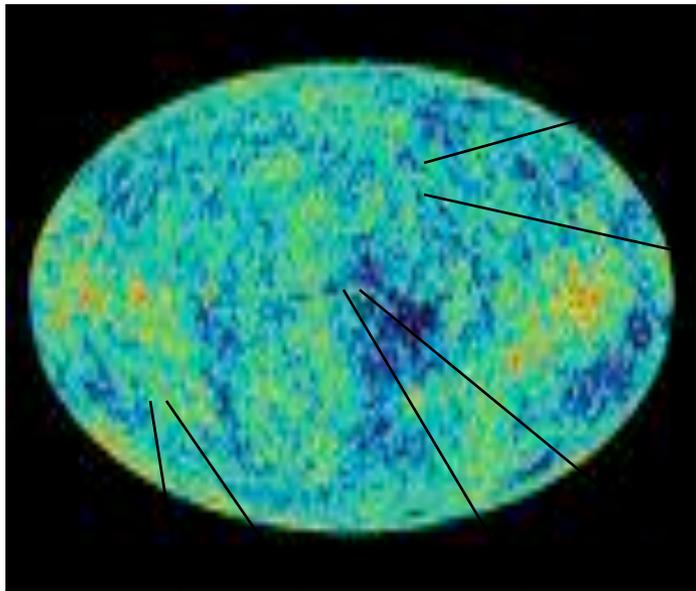


ideal

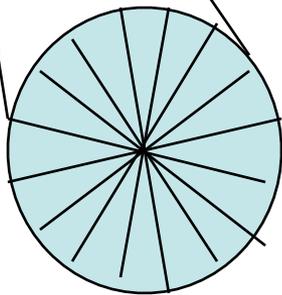
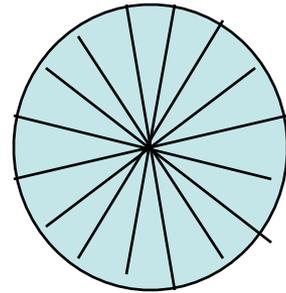
- Removing the quadrupole asymmetry from the scanning strategy eliminates the differential gain and differential beamwidth effects.

Notes on Scan Uniformization

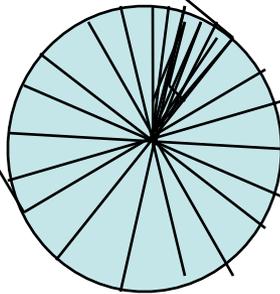
- The text "removing the dipole" and "removing the quadrupole" refer to the multipoles of the scanning strategy, NOT to be confused with the "dipole" and "quadrupole" beam systematic effect.
- Removing the dipole of the scanning strategy eliminates the first order pointing error
- The second order pointing, as well as the differential ellipticity effect do not couple to the scanning strategy and therefore cannot be removed by this way (though might be controlled with others)



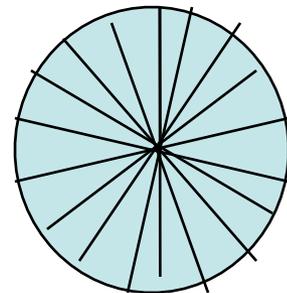
Removing the quadrupole



ideal



Removing the dipole

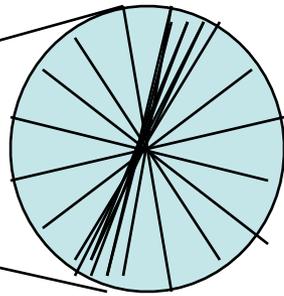
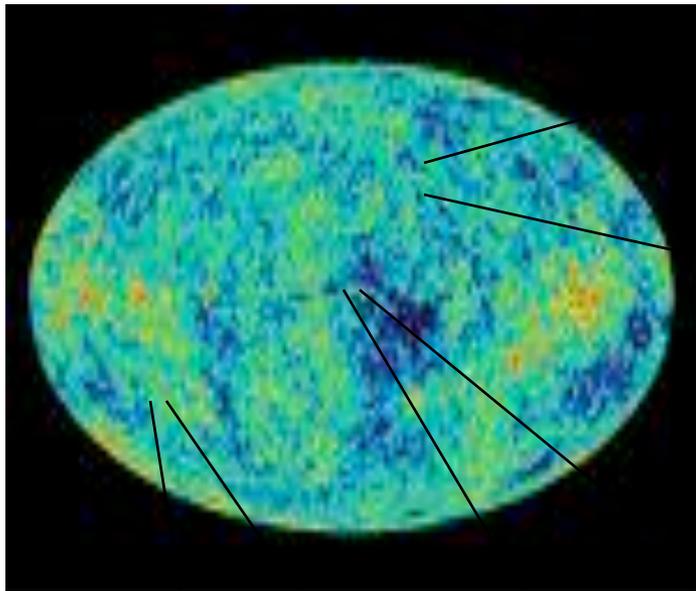


$$N \longrightarrow N(1+f/2)$$

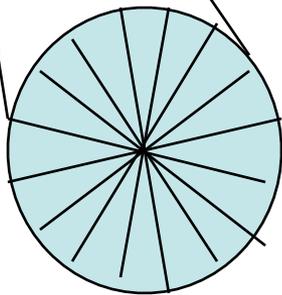
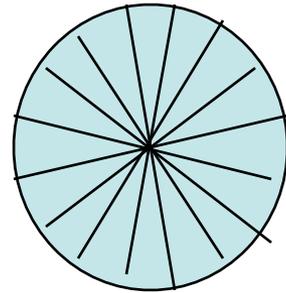
$$\text{Sys} > \text{signal} > N(1+f/2)$$

Cost-benefit analysis of “manually” making the scan uniform

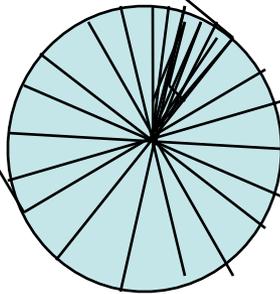
- Assume the instrumental noise level is "N", and that a small fraction "f" of the data is removed, the noise now increases to $\sim N^*(1+f/2)$.
- If the systematics are bigger than the signal $> N^*(1+f/2)$ and if you eliminate the systematics at the expense of increasing the instrumental noise by removing a fraction of your measurements, and you are in the fortunate regime that signal $> N^*(1+f/2)$ still holds, you win....



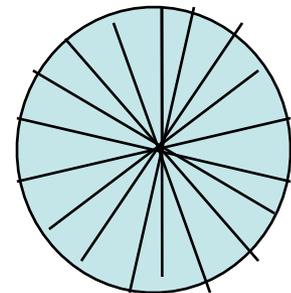
Removing the quadrupole



ideal



Removing the dipole



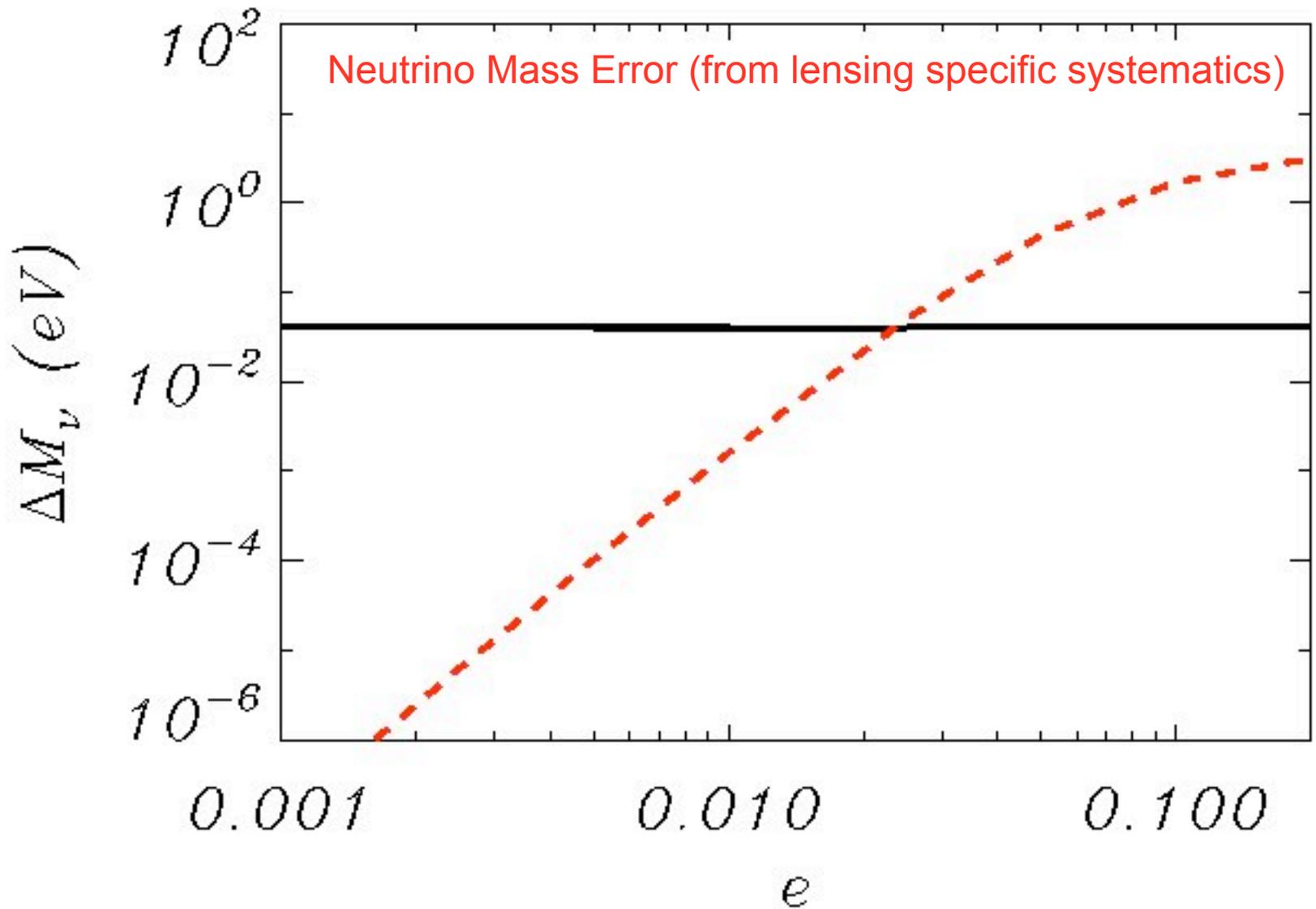
$$N \longrightarrow N(1+f/2)$$

$$\text{Sys} > \text{signal} > N(1+f/2)$$

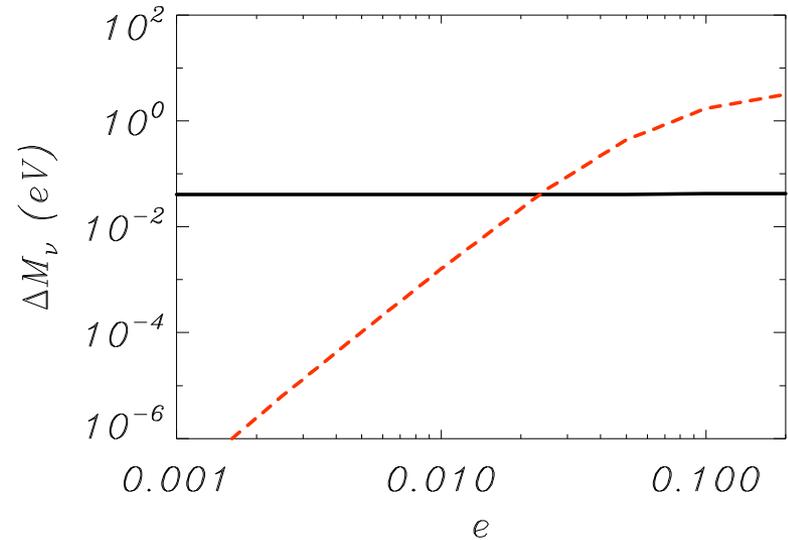
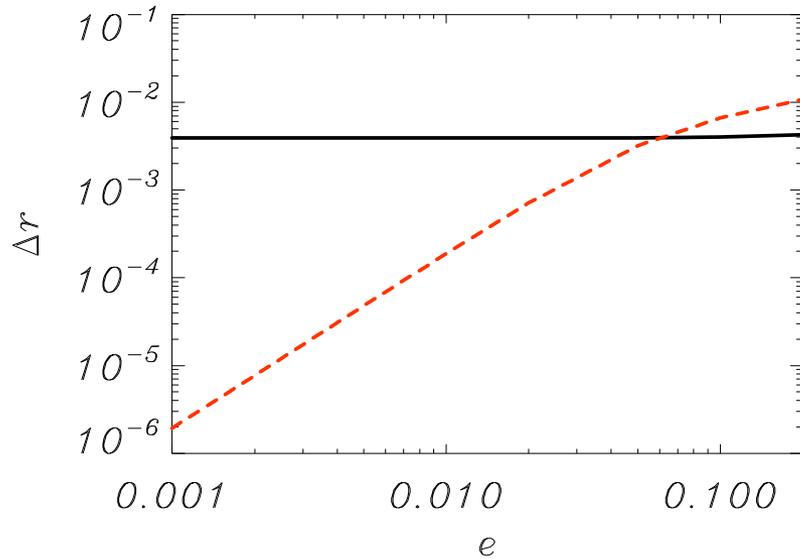
Computational Efficiency

- Systematics that depend on the scanning details can be calculated in two stages:
 - 1. single calculation of the power spectrum of the scanning strategy
 - 2. multiple calculations of the beam-sky coupling (per each cosmological model).
- This significantly speeds-up parameter estimation.

Effect on Parameter Estimation



Uncertainty and Bias (Polarbear)

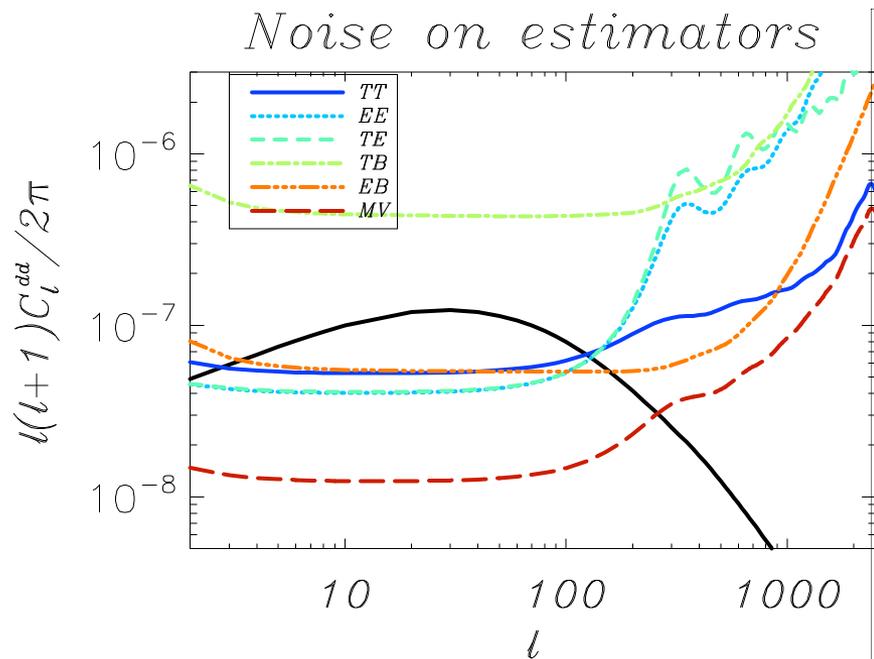


90 GHz: 400 detectors, NEQ/U=310 $\mu K \sqrt{\text{sec}}$

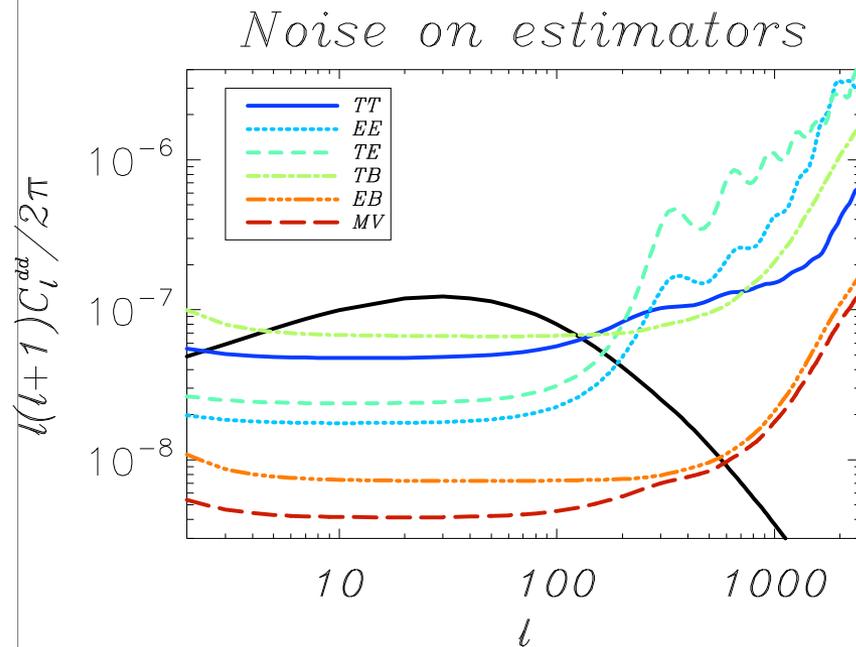
150 GHz: 600 detectors, NEQ/U=345 $\mu K \sqrt{\text{sec}}$

220 GHz: 200 detectors, NEQ/U=640 $\mu K \sqrt{\text{sec}}$

Lensing Reconstruction



POLARBEAR



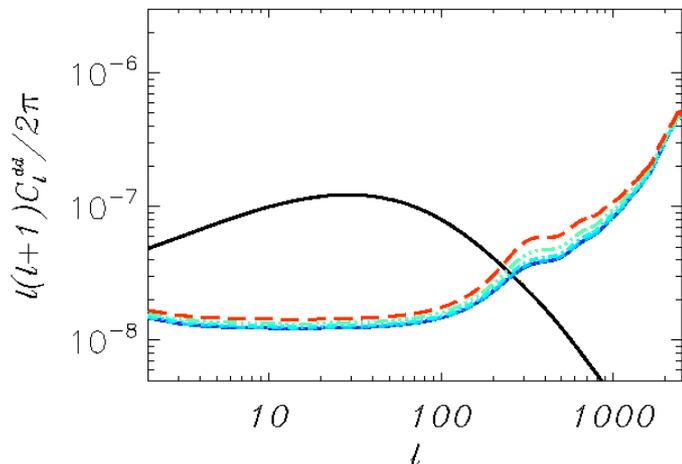
CMBPOL-A

	f-sky	GHz	Res	dT [uK/pix]	dP
Polarbear	0.03	90	6.7'	1.13	1.6
		150	4.0'	1.70	2.4
		220	2.7'	8.00	11.3

	f-sky	GHz	Res	dT [uK/pix]	dP
CMBPOL-A	0.65	150	5'	0.22	0.32

MV in the Presence of Systematics

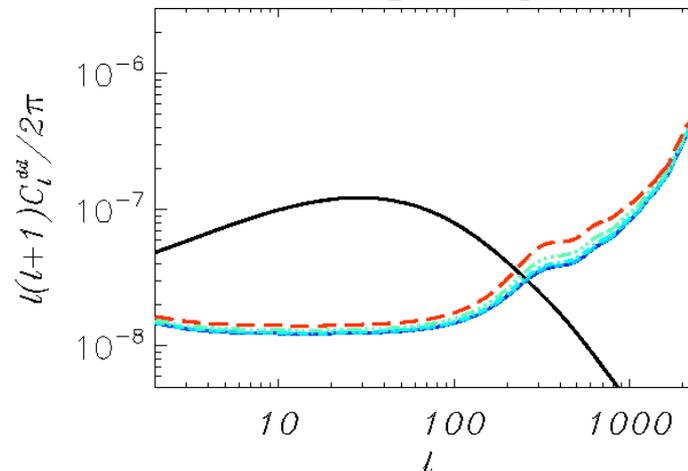
Rotation



Worst Irreducible XPol Effect:

Differential rotation values are (bottom to top) $\varepsilon = 0.01, 0.02, 0.05, 0.10$ and 0.20 radian

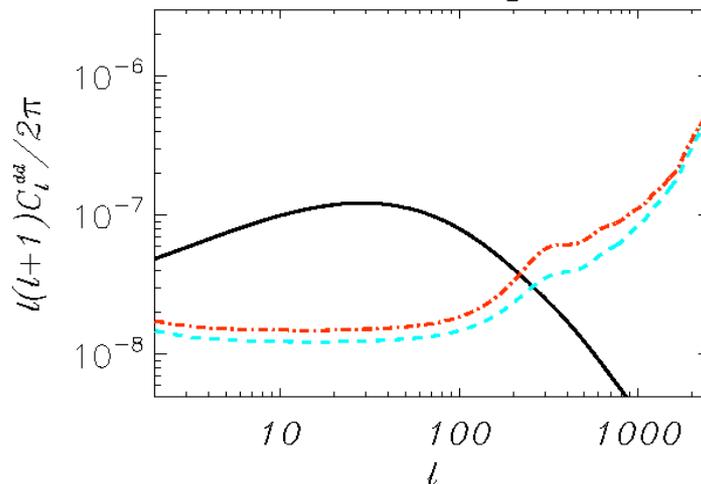
Ellipticity



Worst Irreducible IPol Effect:

Differential ellipticity values are (bottom to top) $e = 0.01, 0.02, 0.05$ and $0.10, 0.20$

Pointing



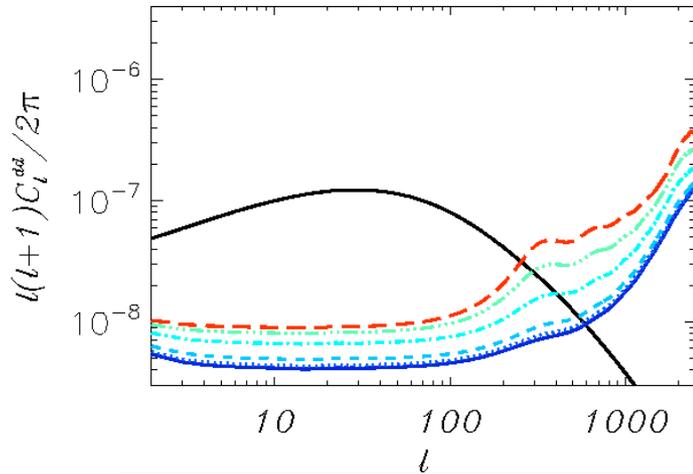
Worst Reducible IPol Effect:

differential pointing with 1% and 10% pointing errors (i.e. $\rho = 0.01\sigma$ and $\rho = 0.1\sigma$, respectively)

POLARBEAR: T

MV in the Presence of Systematics

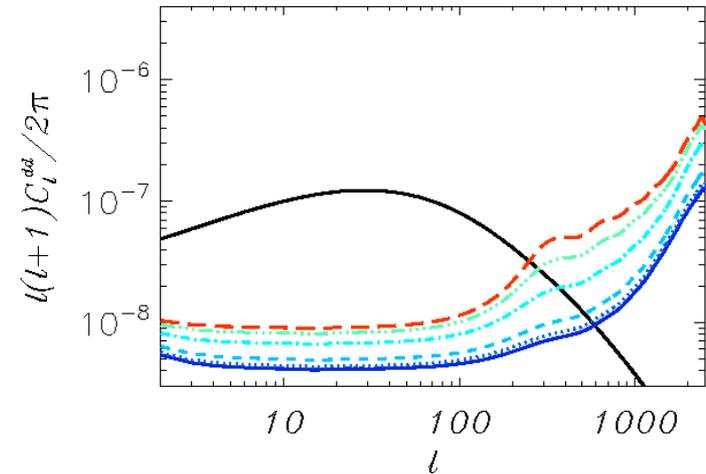
Rotation



Worst Irreducible XPol Effect:

Differential rotation values are (bottom to top) $\varepsilon = 0.01, 0.02, 0.05, 0.10$ and 0.20 radian

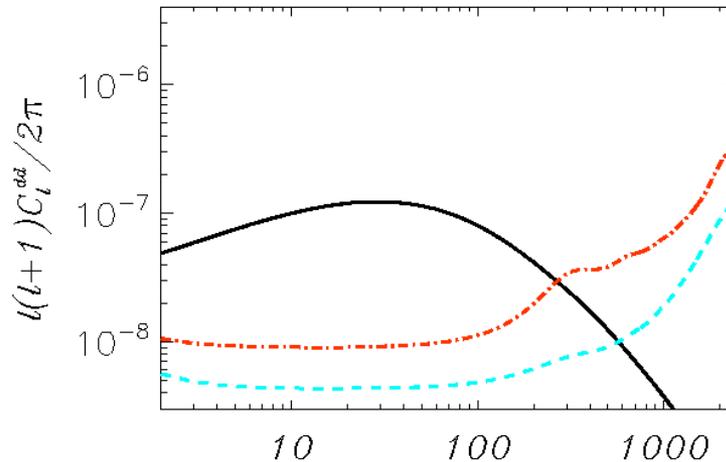
Ellipticity



Worst Irreducible IPol Effect:

Differential ellipticity values are (bottom to top) $e = 0.01, 0.02, 0.05$ and $0.10, 0.20$

Pointing



Worst Reducible IPol Effect:

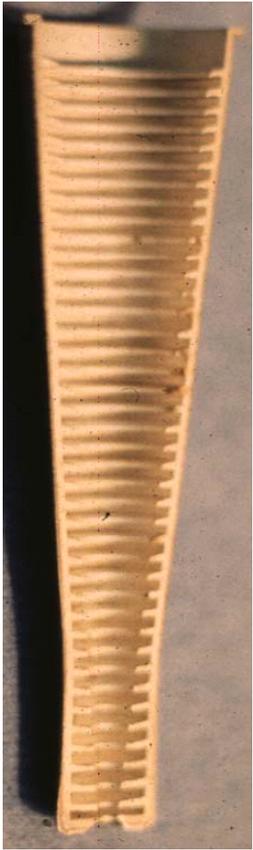
differential pointing with 1% and 10% pointing errors (i.e. $\rho = 0.01\sigma$ and $\rho = 0.1\sigma$, respectively)

CMBPOL-A

Summary

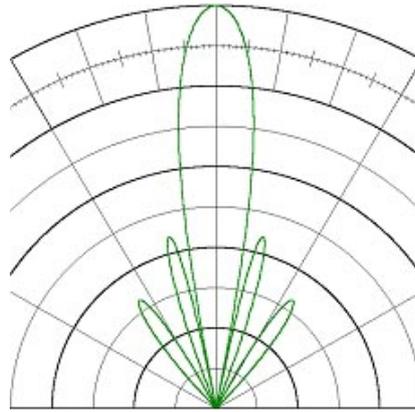
- Fourier space description and Exact calculation of B-mode power spectra including scanning strategy is possible.
- Provide us beam maps and Fourier transform of scan and we can provide you level of MB systematics contamination to r and lensing-derived spectra. (Easier, just provide us with rho, mu etc - assume gaussian).
- Impact on parameter estimation
- Importance of Bias and Monte Carlo simulations

$$Q = \frac{1}{2} [T_1(0^\circ) - T_2(90^\circ)]$$

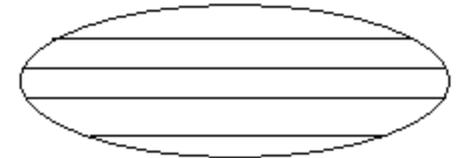
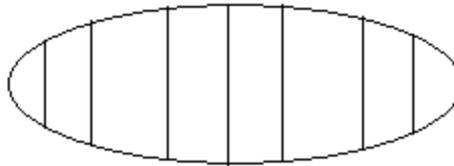
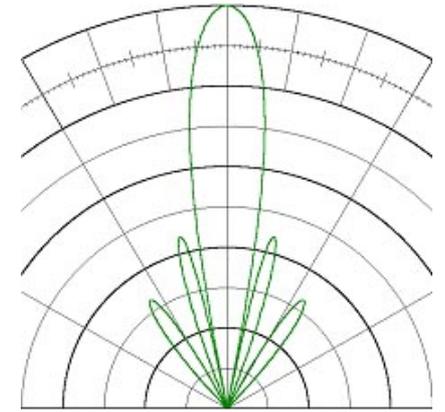


feedhorn

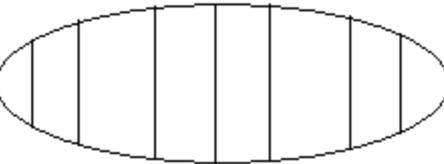
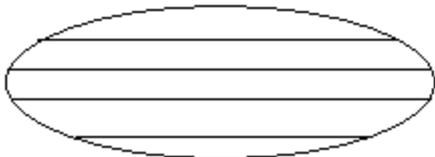
=>



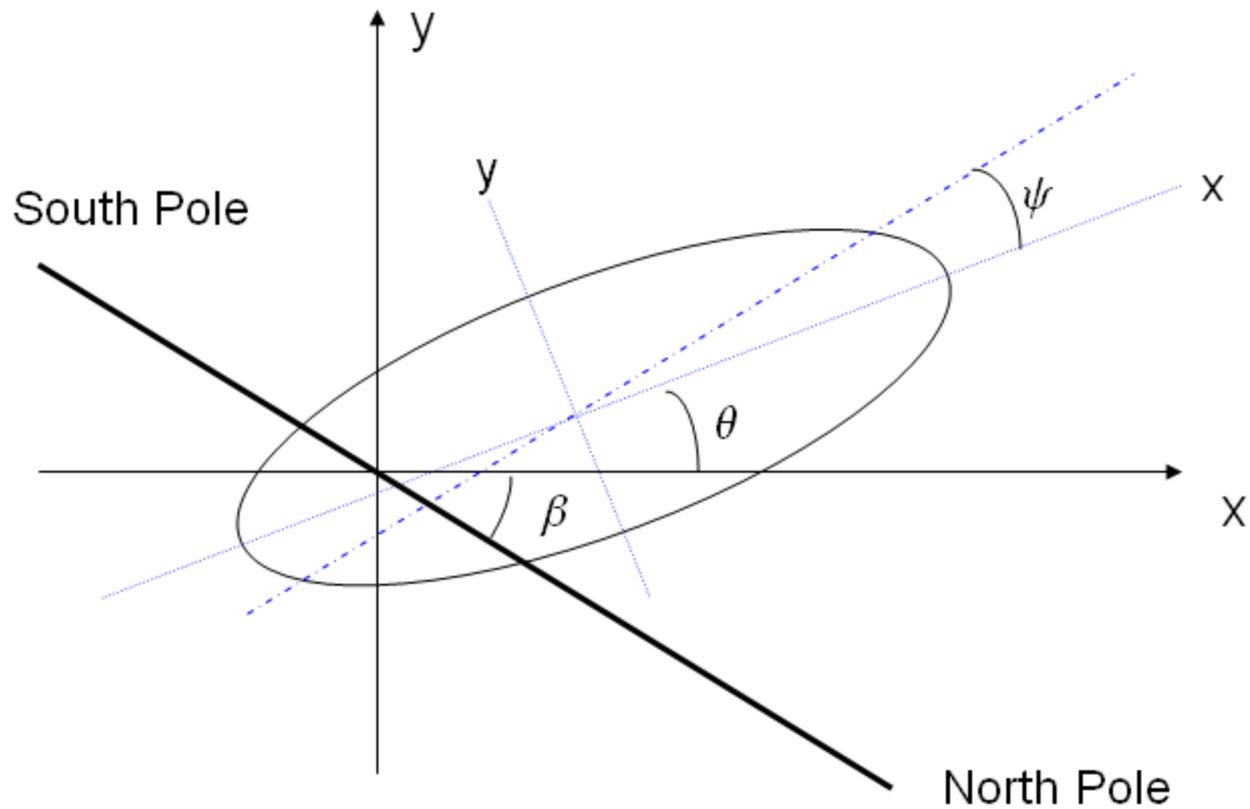
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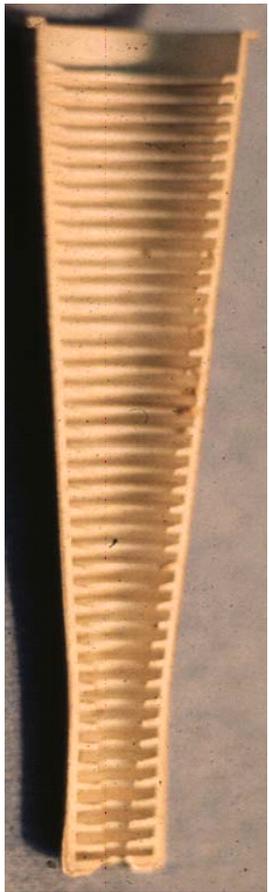


two polarization-sensitive detectors



Beam and angles

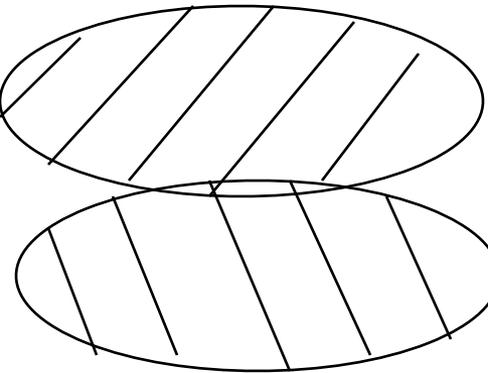
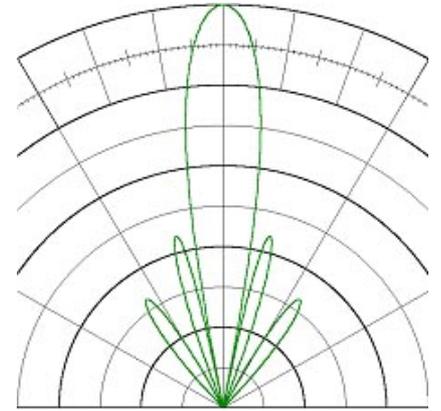
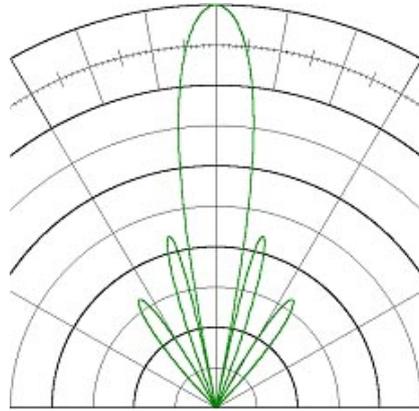




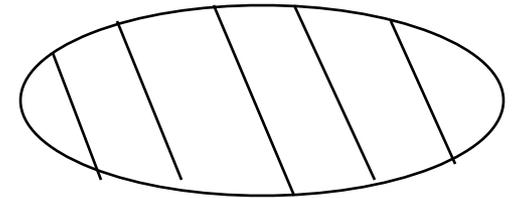
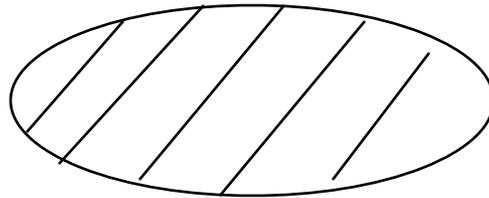
feedhorn

=>

$$U = \frac{1}{2} [T_1(45^\circ) - T_2(135^\circ)]$$



two polarization-sensitive detectors



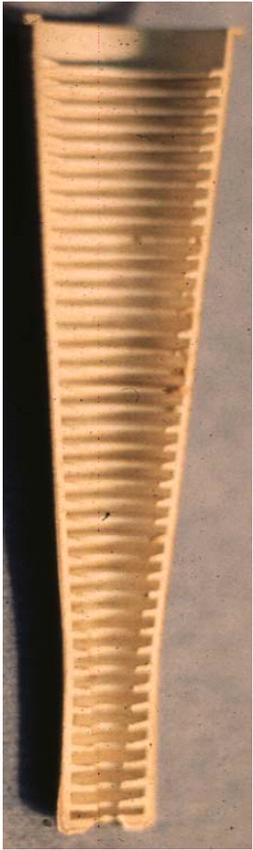
Beam Effects on Polarization

Consider a sky with only unpolarized radiation

$$d = T + \cancel{Q \times \cos 2\alpha} + \cancel{U \times \sin 2\alpha}$$

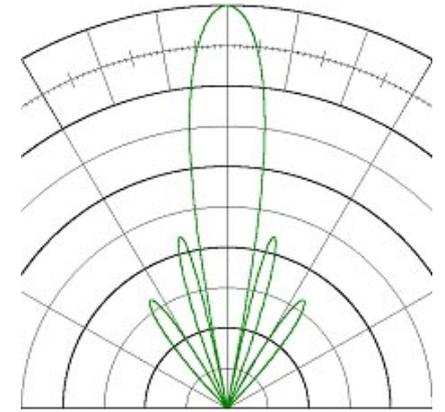
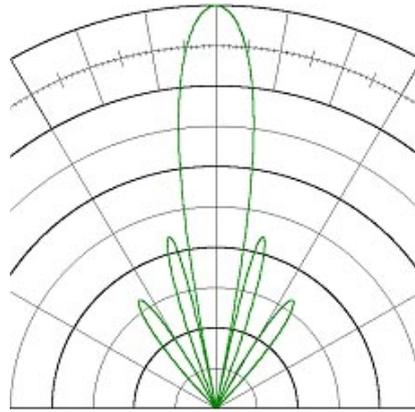
What systematic polarization (aka instrumental polarization) is produced ?

$$Q = \frac{1}{2} [T_1(0^\circ) - T_2(90^\circ)]$$

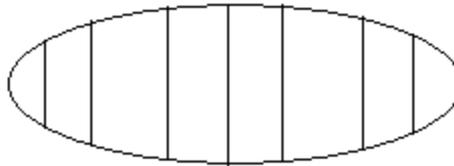


feedhorn

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two polarization-sensitive detectors

