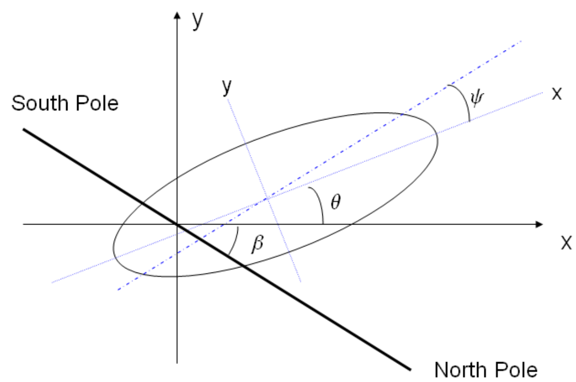
CMB and Beam Systematics



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Brian Keating, Nicolas Ponthieu, Eric Hivon
Dec. 3, 2007

UCSD

Outline

- Motivation
- CMB power spectra
- Beam systematics

Motivation

- Cosmological model depends on a dozen parameters
- Parameter degeneracy and polarization
- Importance of the B-mode
- Susceptibility to temperature leakage

From data Collection to Cosmological Parameters

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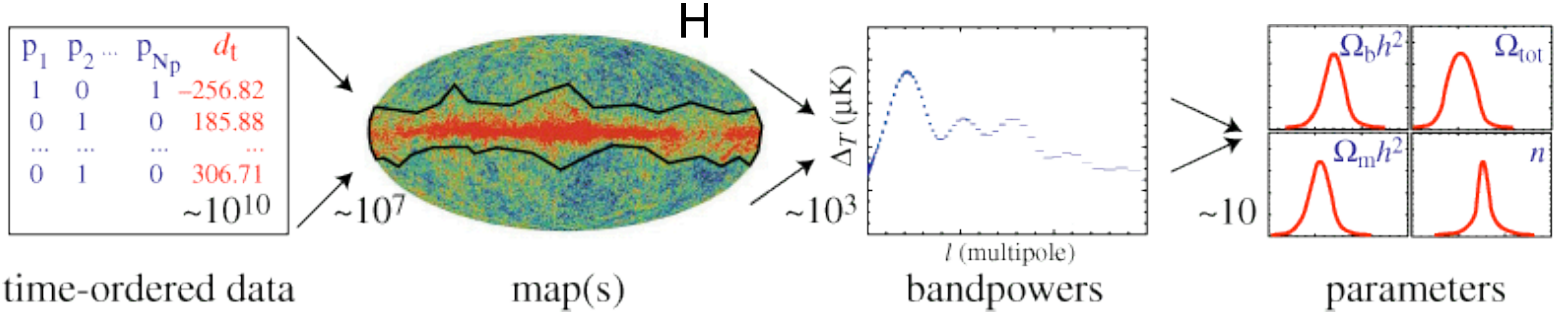


Operational Definition of Q & U

Make a measurement of the sky, d_i

Contains I, Q, U components

Total signal

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

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

$$U = \frac{1}{2}[d(45^0) - d(135^0)]$$

Polarization Field

- Define the polarization field (tensor of rank 2) and its Fourier transform (Q and U are the Stokes parameters)

$$Q' + iU' = (Q + iU)e^{2i\phi_x}$$

$$Q + iU = \int \frac{d^2\vec{l}}{2\pi}\left[E(\vec{l}) + iB(\vec{l})\right]e^{2i\phi_l}e^{i\vec{l}\cdot\vec{\theta}}$$

E and B are the Fourier coefficients of the polarization field

CMB Power Spectra

- Power spectra in the flat sky

$$C_l^{XY} = \frac{\int X(\vec{l})Y^*(\vec{l})d\phi_l}{2\pi}$$

$$X, Y \in \{T, E, B\}$$

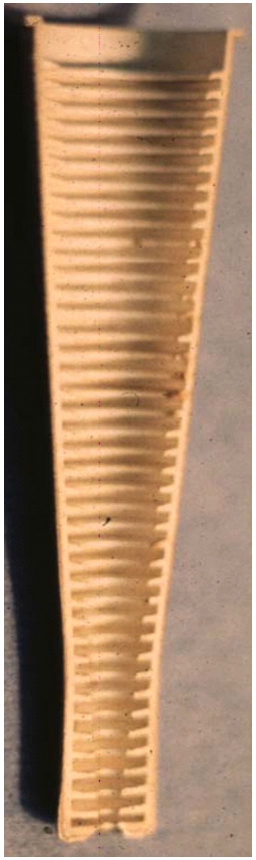
Beam Effects on Polarization

Consider a sky with only unpolarized radiation

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

What systematic polarization (aka instrumental polarization) is produced ?

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



feedhorn

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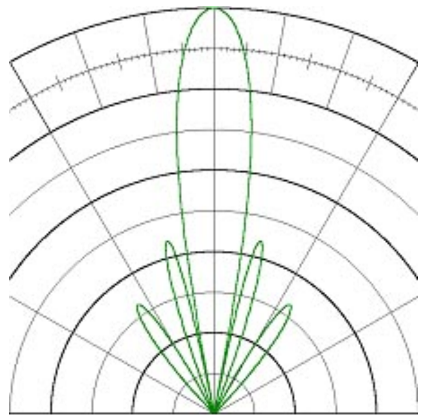

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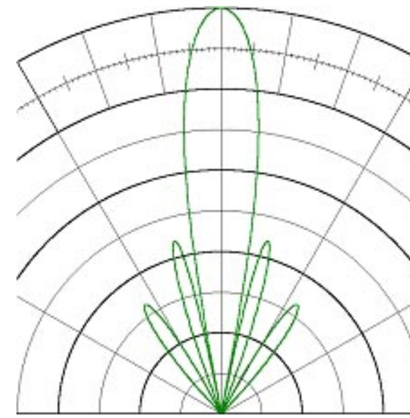
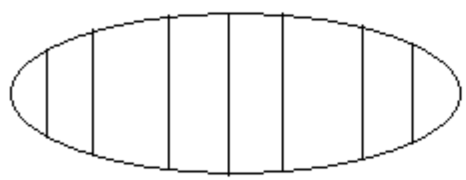
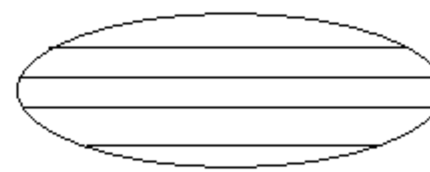
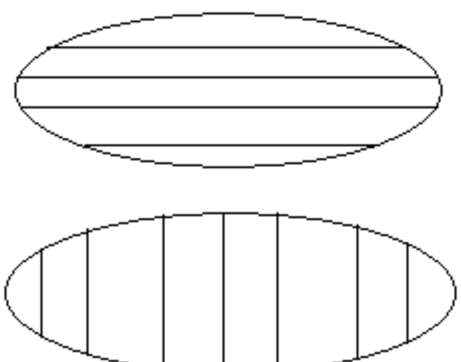






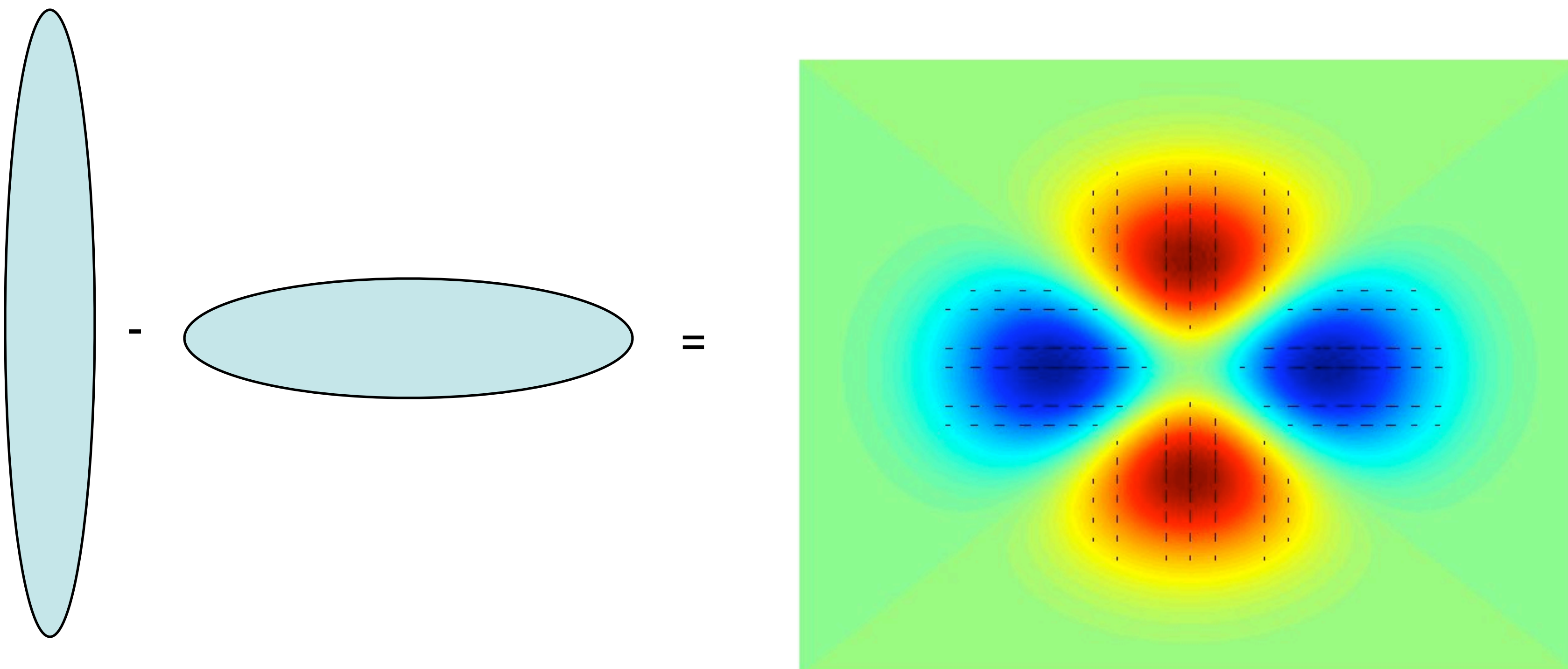


two polarization-
sensitive
detectors

Differential Beam Systematic Ellipticity

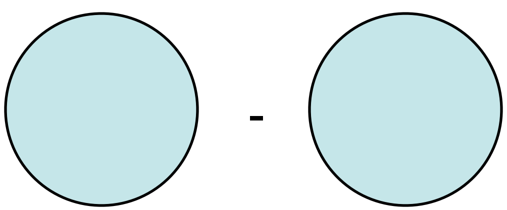
T_1 T_2

For an unpolarized point source



Differential Beam Systematic Pointing

T_1 T_2



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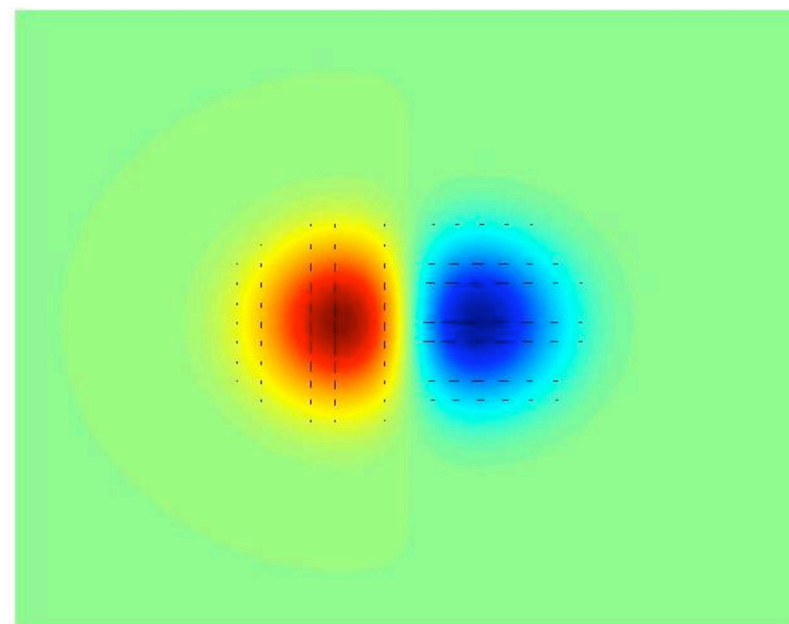
For an unpolarized point source



Beam Function

Real space:

$$T(\vec{x}) \circledR \; T \otimes B$$

$$B(\vec{x}) = \frac{1}{2\pi\sigma_x\sigma_y}\exp[-\frac{(x-\rho_x)^2}{2\sigma_x^2} - \frac{(y-\rho_y)^2}{2\sigma_y^2}]$$

Fourier space:

$$\widetilde{T}_l \circledR \; \widetilde{T}_l \times \widetilde{B}_l$$

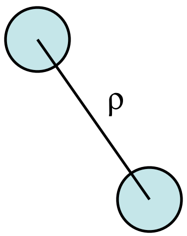
$$\widetilde{B}(\vec{l}) = \exp(-\frac{l_x^2\sigma_x^2}{2} - \frac{l_y^2\sigma_y^2}{2} + i\vec{l} \times \vec{\rho})$$

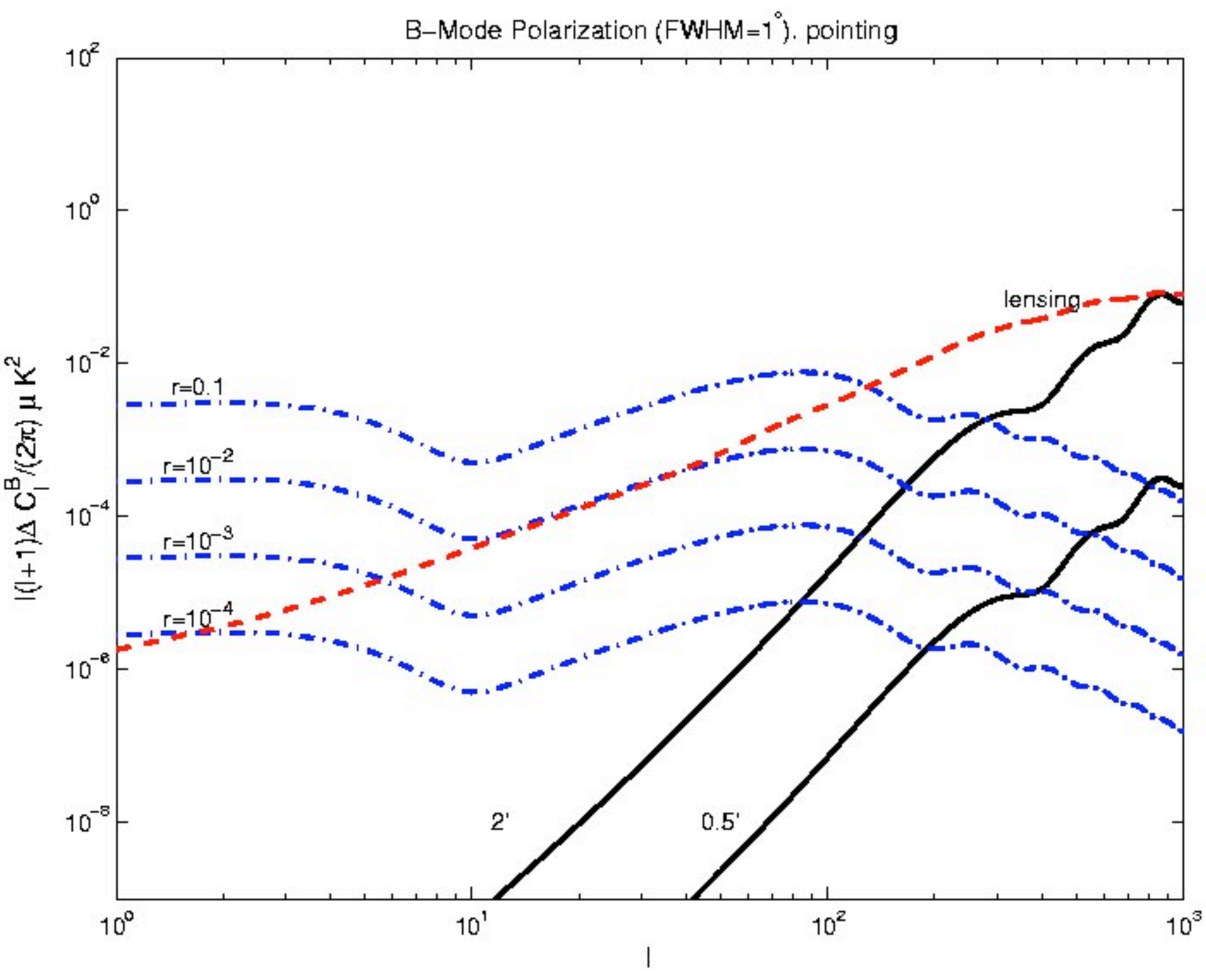
$$\widetilde{Q}(\vec{l}) = \frac{1}{2}[\widetilde{B}_1(\vec{l}) - \widetilde{B}_2(\vec{l})] \times \widetilde{T}(\vec{l})$$

Results

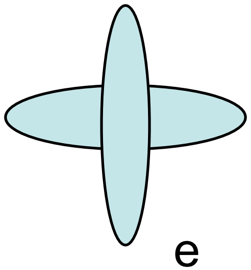
- Working in Fourier space from the outset
- Reducible and irreducible systematics
- Full analytic description, including scanning strategy, readily applicable for any beam shape

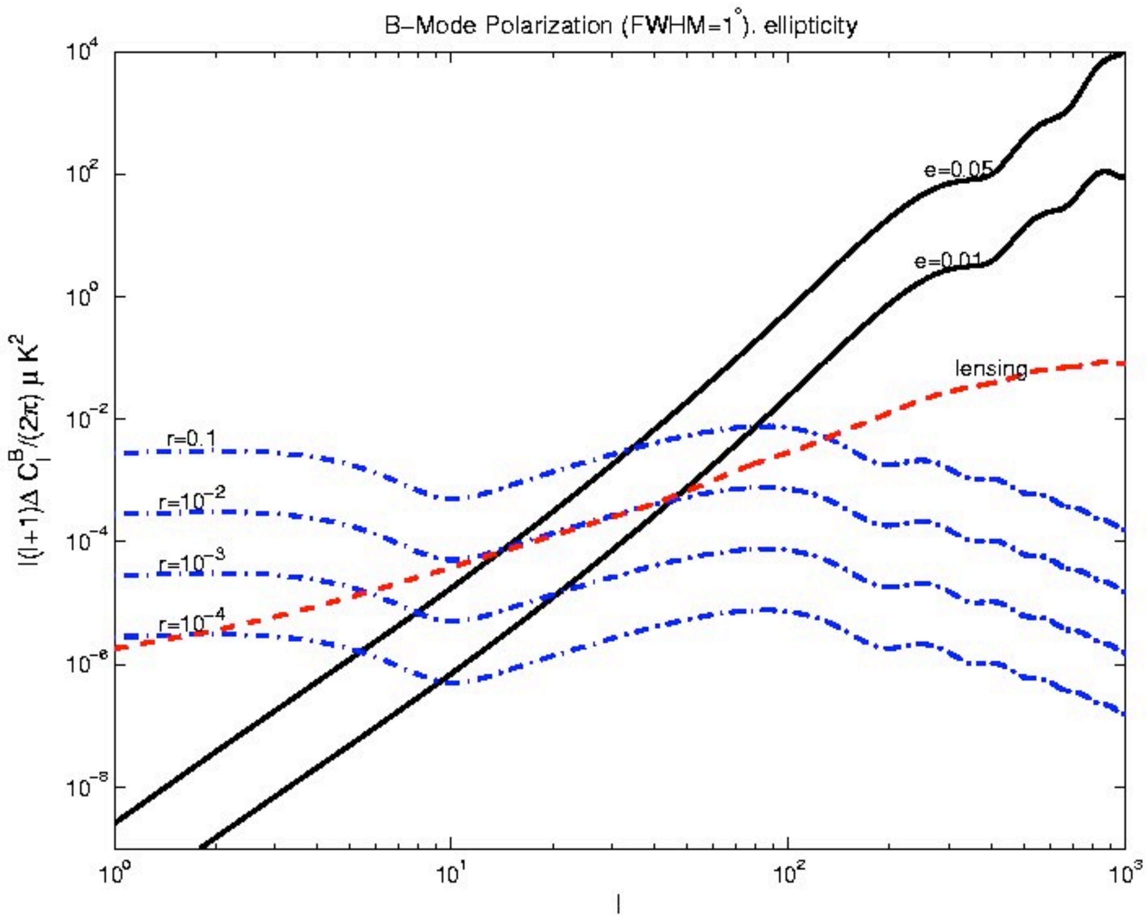
B-Mode Polarization (1 degree beam), Diff. Pointing



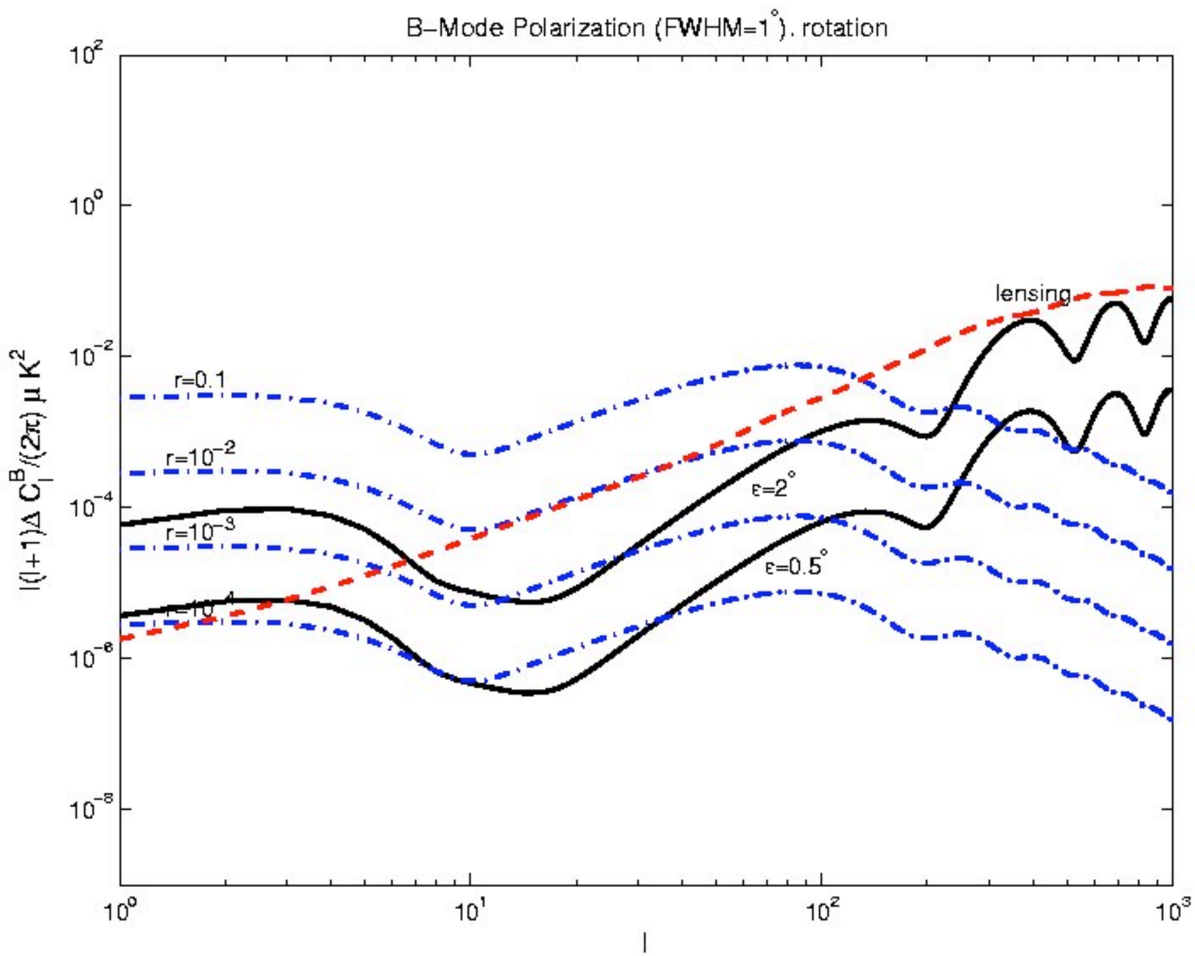


B-Mode Polarization (1 degree beam), Diff. Ellipticity





B-Mode Polarization (1 degree beam), Diff. Rotation



Summary

- Fourier space description
- Exact calculation of B-mode power spectra including scanning strategy
- Impact on parameter estimation

Shimon, Keating, Ponthieu and Hivon (2007), PRD accepted

Miller, Shimon and Keating, to be submitted

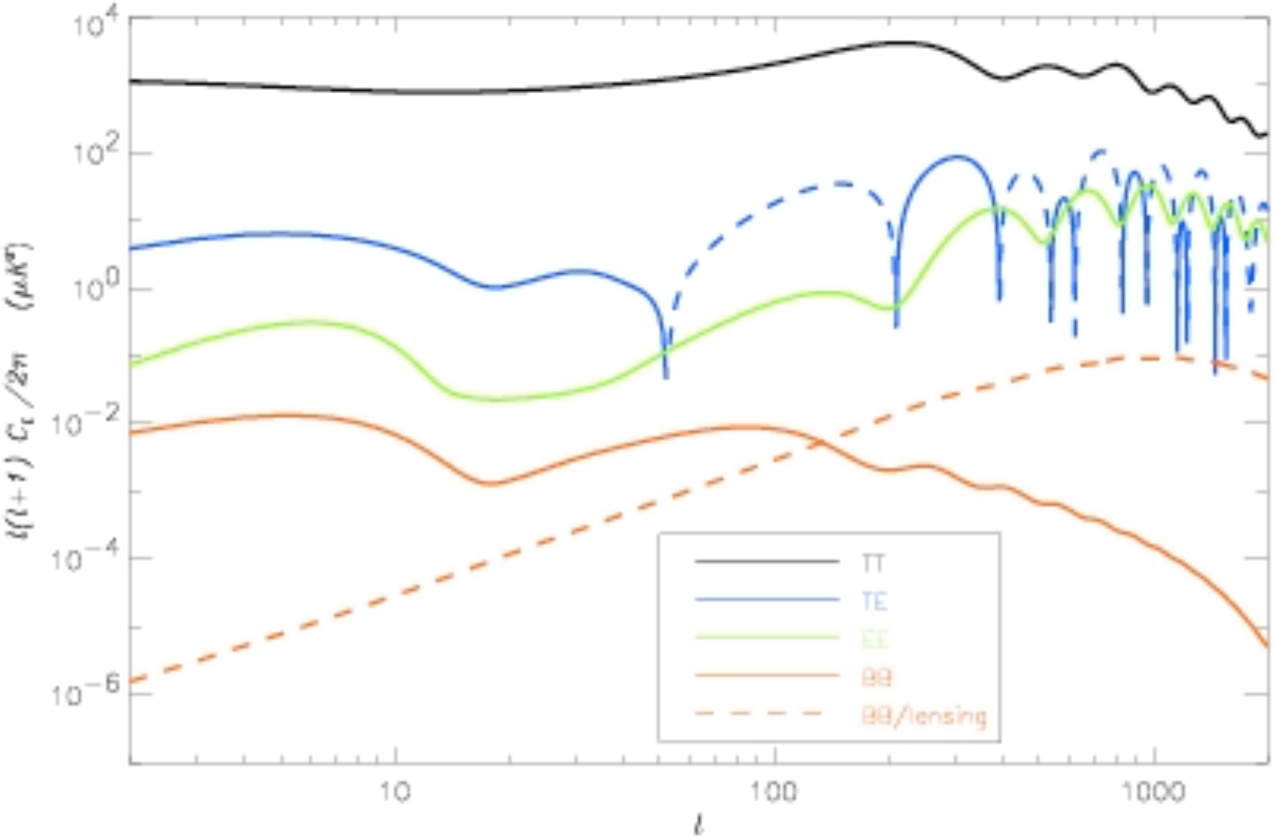
Acknowledgments

- Evan Bierman
- Nathan Miller
- Tom Renbarger
- Jamie Bock

All Spectra Together

CAMB

$$\theta^\circ \approx \frac{180}{l}$$



Electric Field and Polarization

$$E_x = E_{0x} \cos(kz - wt + \delta_x)$$

$$E_y = E_{0y} \cos(kz - wt + \delta_y)$$

$$I = | E_x |^2 + | E_y |^2$$

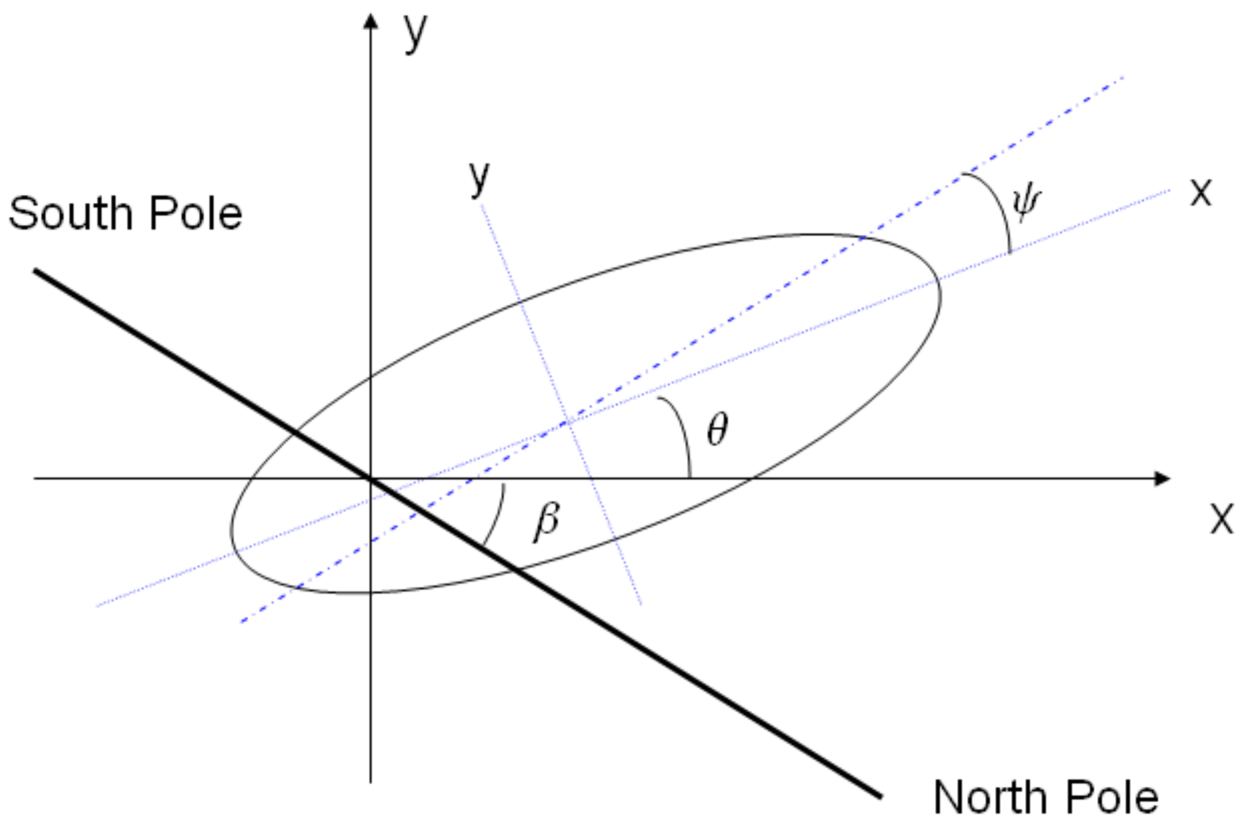
Instensity

$$Q = | E_x |^2 - | E_y |^2$$

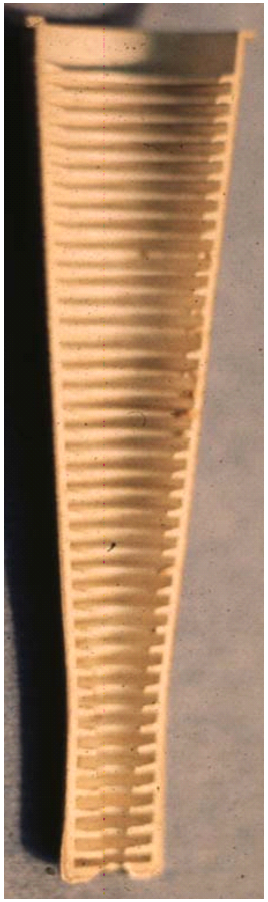
Stokes parameters

$$U = 2\,\mathrm{Re}(E_x E_y)$$

Beam and angles



$$U = \frac{1}{2}[T_1(45^0) - T_2(135^0)]$$



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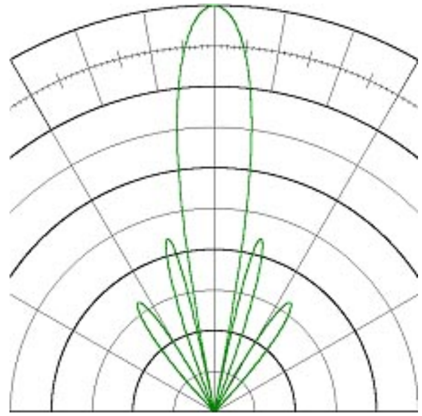

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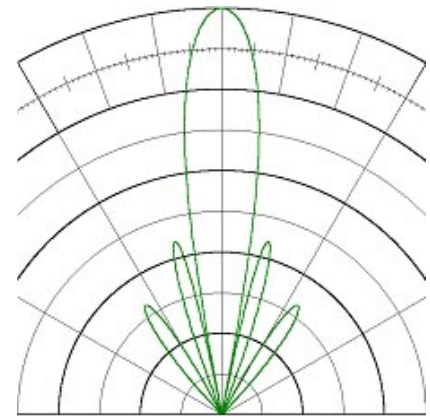

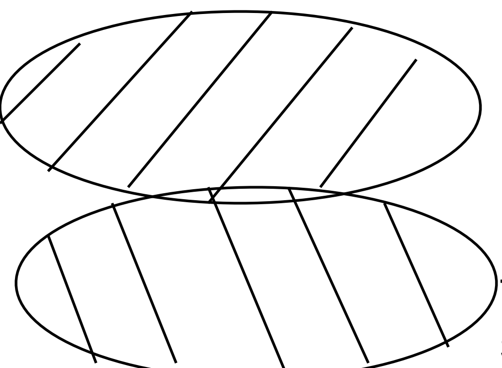

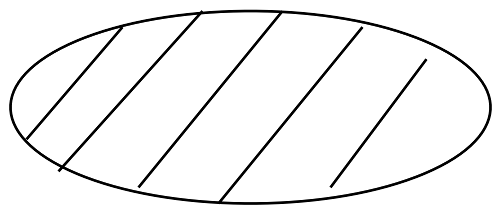

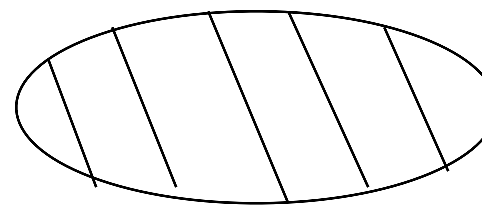

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