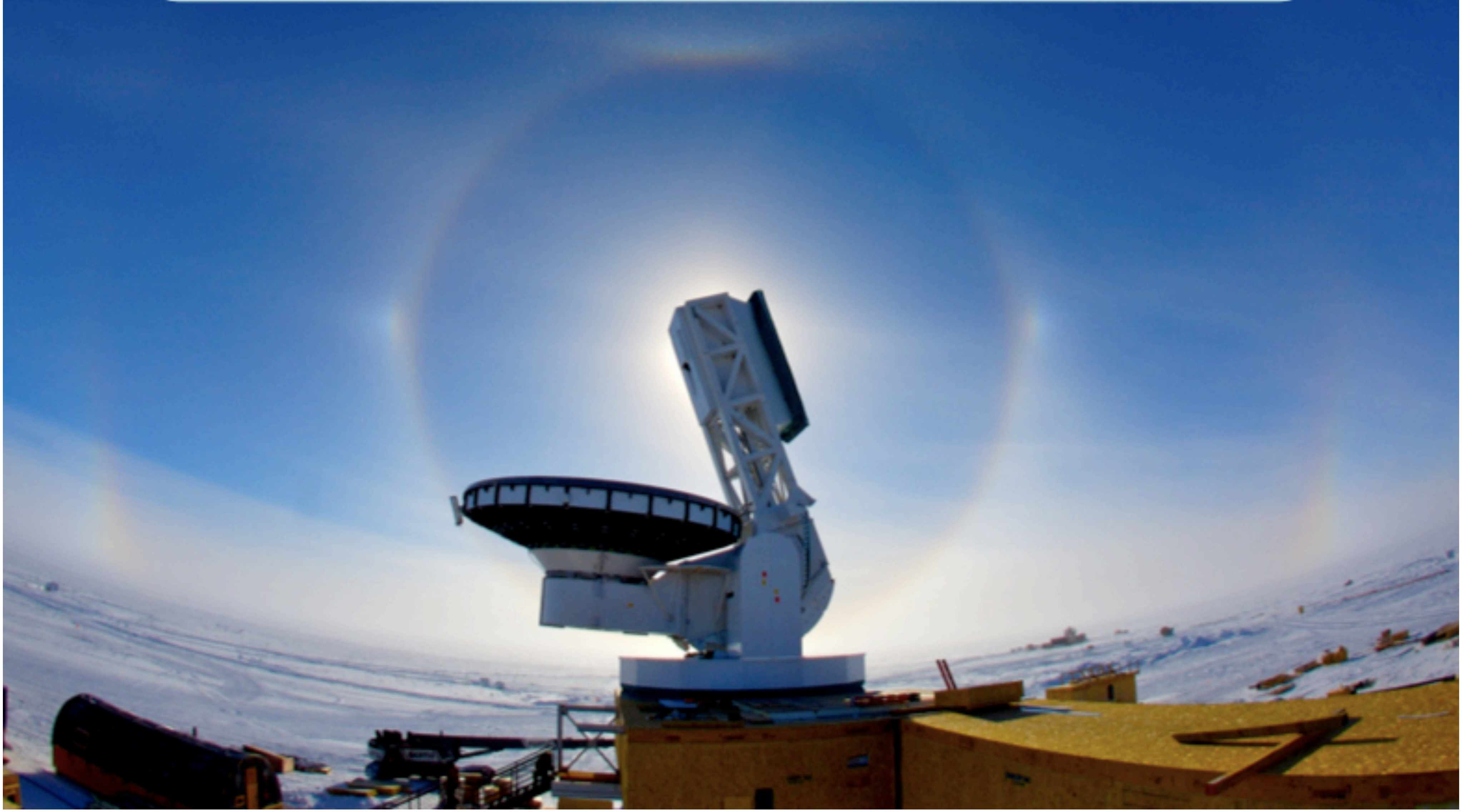
SPTpol Systematics

Jeff McMahon (for the SPT collaboration)

Inflation Probe Systematics Workshop

Annapolis, MD, July 28-30



SPT collaboration

Chicago
Carlstrom
Hu
Kravtsov
Meyer
Pryke
Aird
Leitch
Padin
Chang
Crawford
McMahon
Miknaitis
Keisler
Bleem
Crites
Vieira

Case
Ruhl
Staniszewski

Berkeley/LBNL
Holzapfel
Lee
White
Spieler
Benson
Reichardt
Lueker
Plagge
Shirokoff
Zahn

McGill
Dobbs
Holder
Shaw

SAO
Stark

Illinois
Mohr

Cardiff
Filters
Ade

Boulder
Halverson

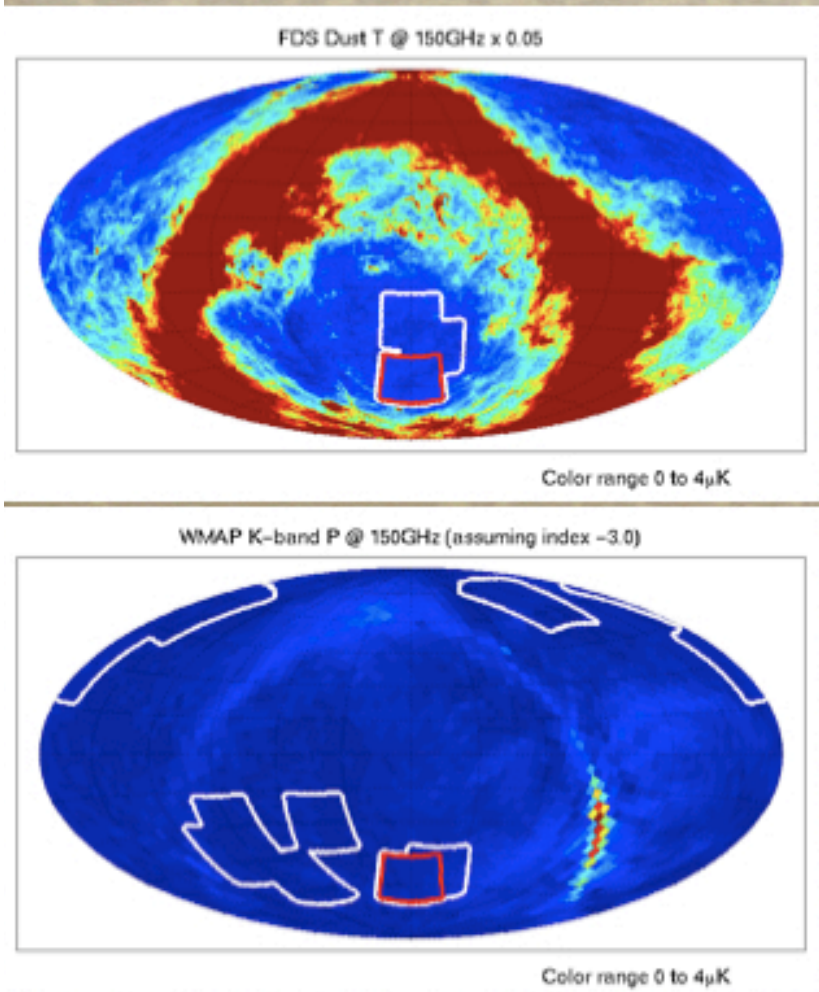
Davis
Knox

MSFC
Joy

SPTpol Summary Table

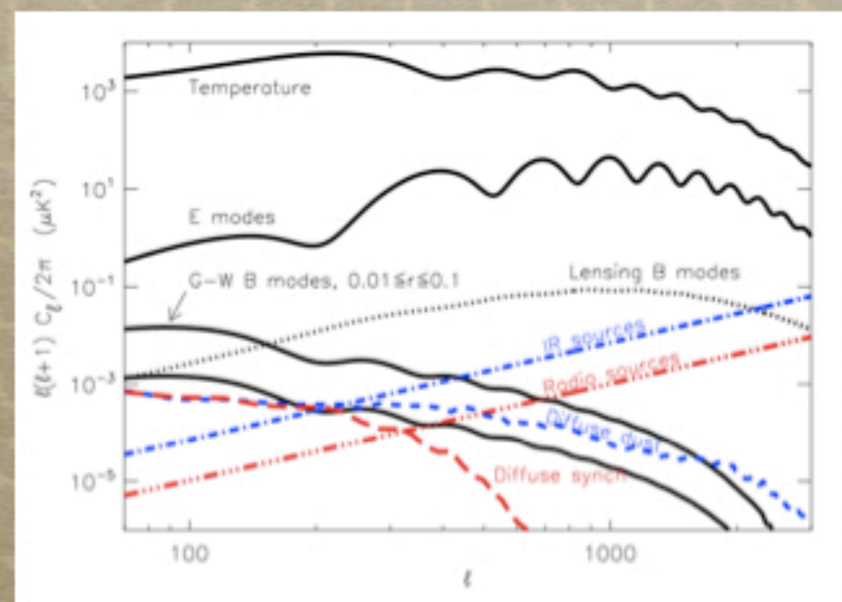
Angular resolution	1.6, 1.0, 0.8	Arcminutes
Frequency Coverage	90, 150, 220	GHz
Sky Coverage	600	Square Degrees
Multipole Coverage	50-10000	-
Polarization Modulation?	HWP?	-
Types of Detectors	Bolometer, differencing	-
Location	Ground, South Pole	(Balloon/Ground/Space)
Instrument NEQ	14	$\mu K\ s^{1/2}$
Expected/Current limit on *r*	0.01 ($\sigma(r) = 0.004$)	-
Status	Funded	(Funded/Proposed/ Future)

Foregrounds



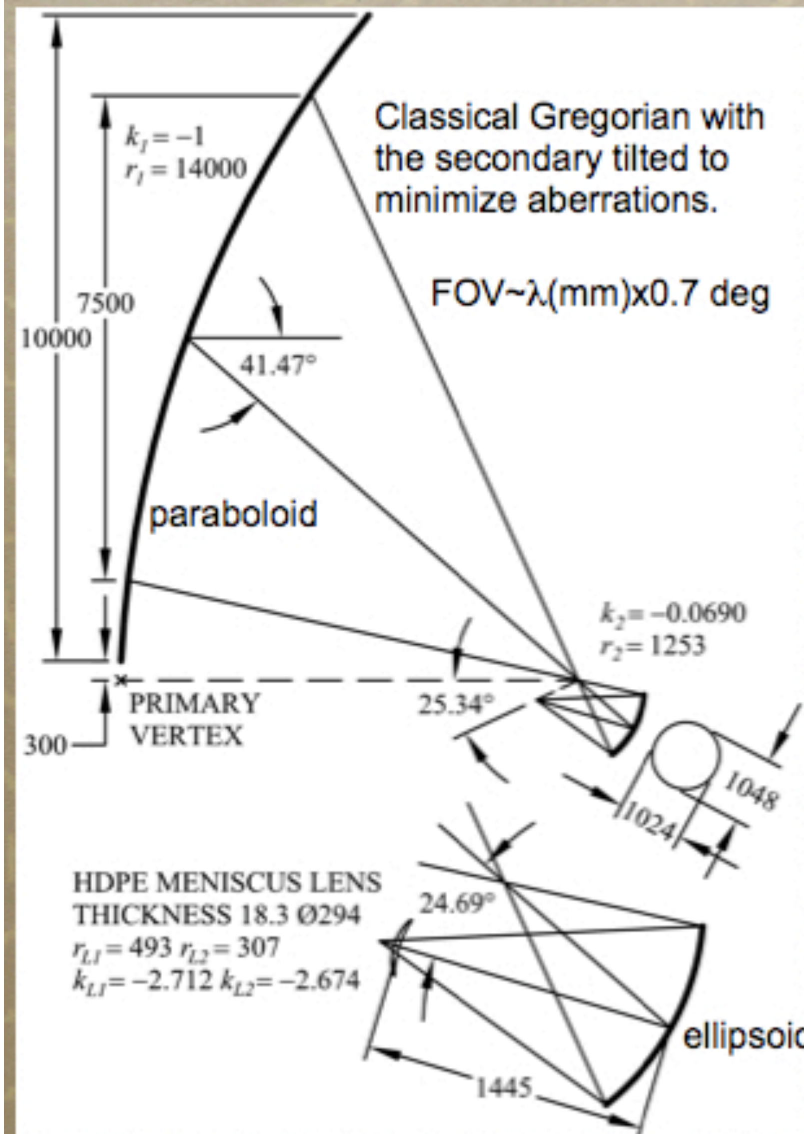
C. Pryke

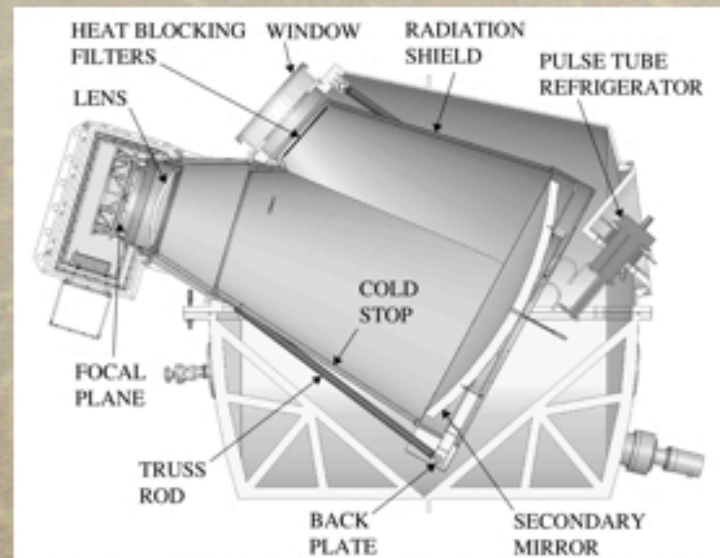
There is a really clean patch of sky accessible 24 hours a day from the South Pole!



Tom Crawford

SPT optics





- Low background, low sidelobe optics
- Cooled secondary
- Accommodates 1000 elements
- Introduction of a wave plate is possible

Scan Strategy

- *Candidate scan-strategies (which allow the removal of ground synchronous signals)*
  - *Lead-trail (Az only)*
  - *Elevation-drift scan*
- *South Pole is a unique place on the earth*
  - *Positives: cold, dry, stable*
  - *Features:*
    - *parallactic angle doesn't changes with Earth's rotation*
    - *position of sidelobes are fixed on sky relative to main beam*

Systematics

Approach: Consider effects i

Systematic	Effect
Crosspolar beam	$E \rightarrow B$
Polarization angle errors	$E \rightarrow B$
Pointing errors (on Q/U)	$E \rightarrow B$
Main beam asymmetry (before differencing)	$dT \rightarrow B$
Sidelobes	$dT \rightarrow B$
Instrumental polarization	$dT \rightarrow B$
Relative calibration errors	$dT \rightarrow B$
Pointing errors before differencing	$T \rightarrow B$
Gain drift before differencing	$T \rightarrow B$
Optics and spillover T variations	$dT_{opx} \rightarrow B$
Scan modulated cold stage variations	$dT_{CS} \rightarrow B$
Band shape errors, including modulator effects	foregrounds $\rightarrow$ B
Others?	?

Effect in map space (Following HHZ)

monopole dipole, quadrupole E<->B

E<->B rotation

"lensing like" deformation of map

quadrupole T-> E, B

higher order T-->E,B coupling

monopole T->E,B

monopole T->E,B

dipole T->E,B

monopole T->E,B, time varying

Scan synchronous Noise

Scan synchronous Noise

Band Pass errors

Scan Strategy: ground pickup

The response of the telescope is given by:

$$R(\hat{n}) = \int SB(\hat{n})d\Omega$$

So scan synchronous signal is

$$\frac{dR(\hat{n})}{d\hat{n}} = \int S\frac{dB(\hat{n})}{d\hat{n}}d\Omega$$

- Scan synchronous signals generated by side-lobes coupled to emitting structures matched to the scan strategy. The South Pole is nearly featureless.
- Current unpolarized observations limit pickup below 10 μK below 0.5° scales (limited by 1/f)

Scan Strategy: sky pickup

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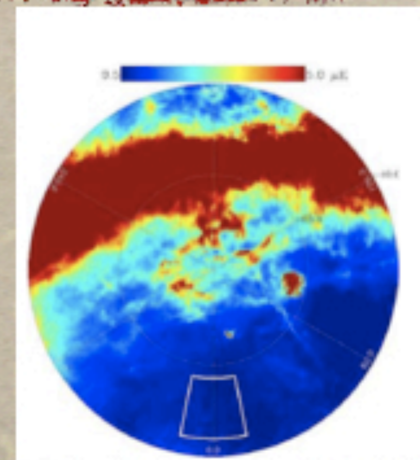
So scan synchronus signal is;

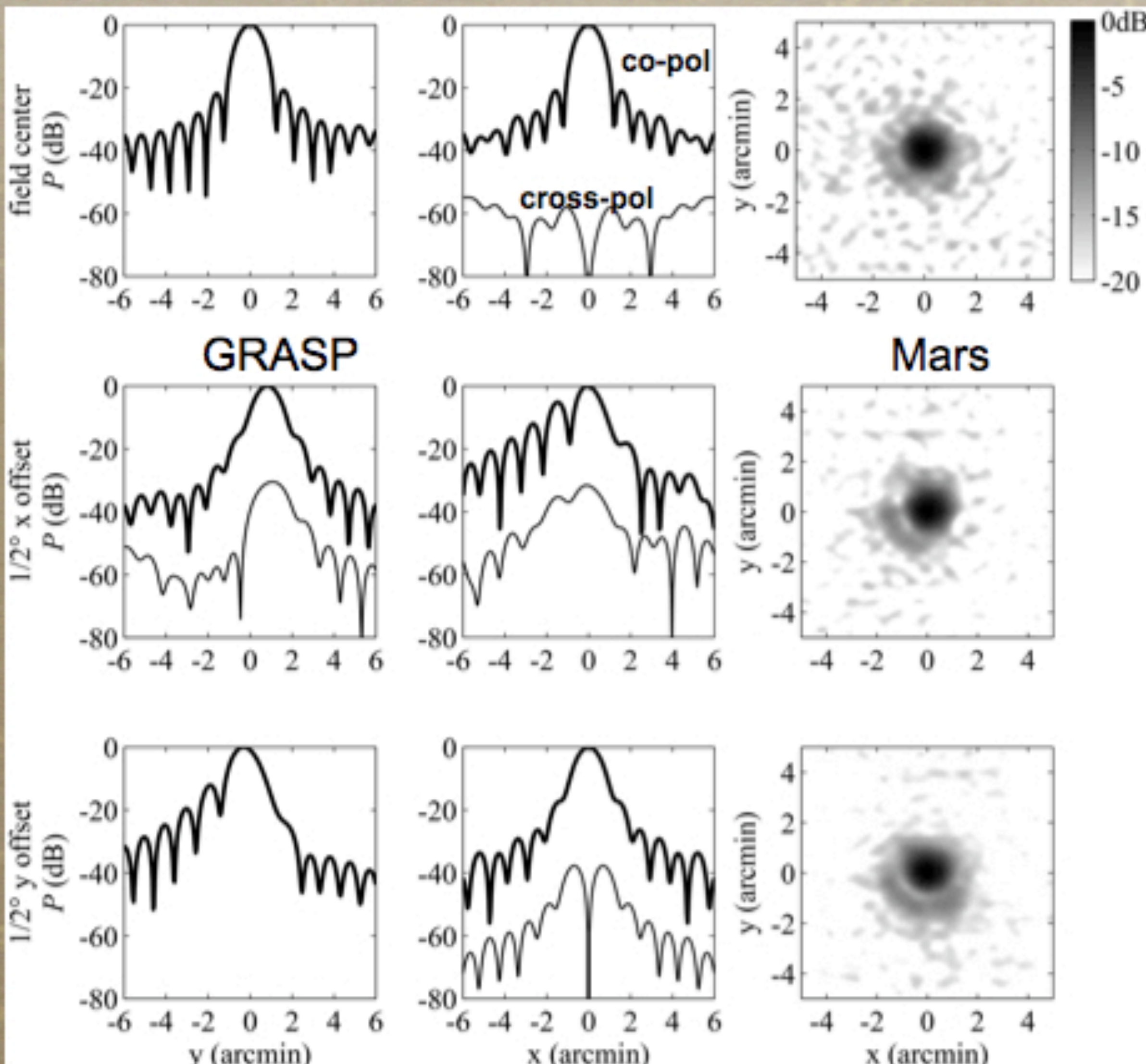
$$\frac{dR(\hat{n})}{d\hat{n}} = \int S\frac{dB(\hat{n})}{d\hat{n}}d\Omega$$



- *Plan: Measure far side-lobes then improve the optics to eliminate any large lobes*
- *How hard is that? (depends on angular scale)*
  - *- for 600 sq degrees @1K, -55dBi gives ~ 40 nK undifferenced*
  - *- requires ~100 mW of source power to measure in a few hours*
  - *- once we have a side-lobe measurement we can refine the requirement*

SPT beams

λ=2mm



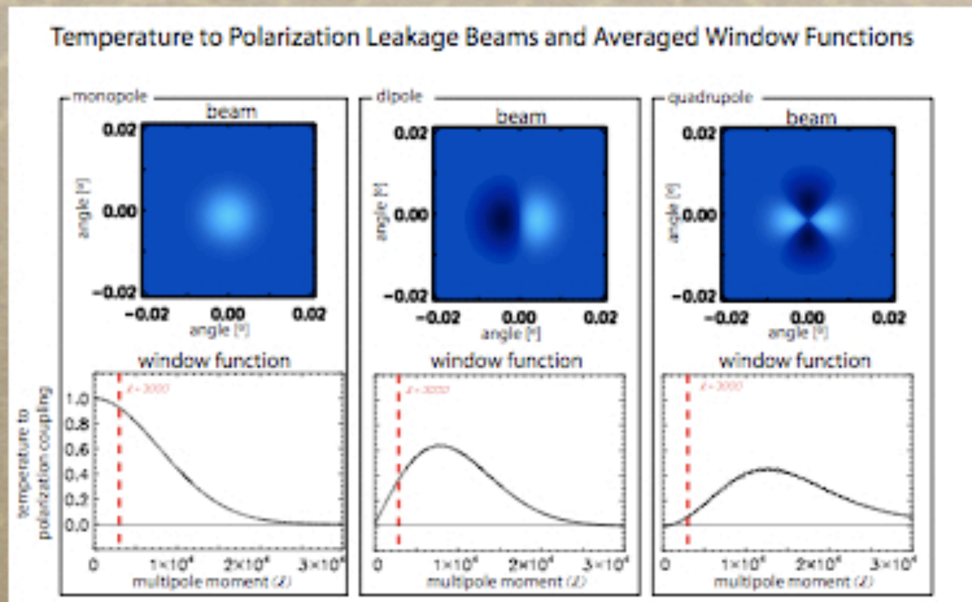
- I->P leakage
  monopole term dominated by A-B gain mismatch ~-20dB

  From beam simulations
  dipole ~ -20dB peak
  quadrupole ~ -20dB peak

- cross-polar E->B leakages
  from optics below -35dB
  => dominated by uncertainty in detector angle

Effects Mixing I and (Q,U)

Calculation for the particular case of the South Pole Telescope (1 arc minute beam)



Cause:	instrument polarization A-B gain mismatch	cross-polarization A-B pointing differnce	cross-polarization, 'elliptical' beams

- Convenient to think of all effects mixing I->Q/U as **'leakage beams'** connecting T on the sky to measured Q/U
- This formalism handles instrument specific effects on a unified footing

Two sources of suppression geometric / optical design
- smaller beams better geometric suppression
- dipole suppressed by parallactic angle rotation
  quadruple is not!

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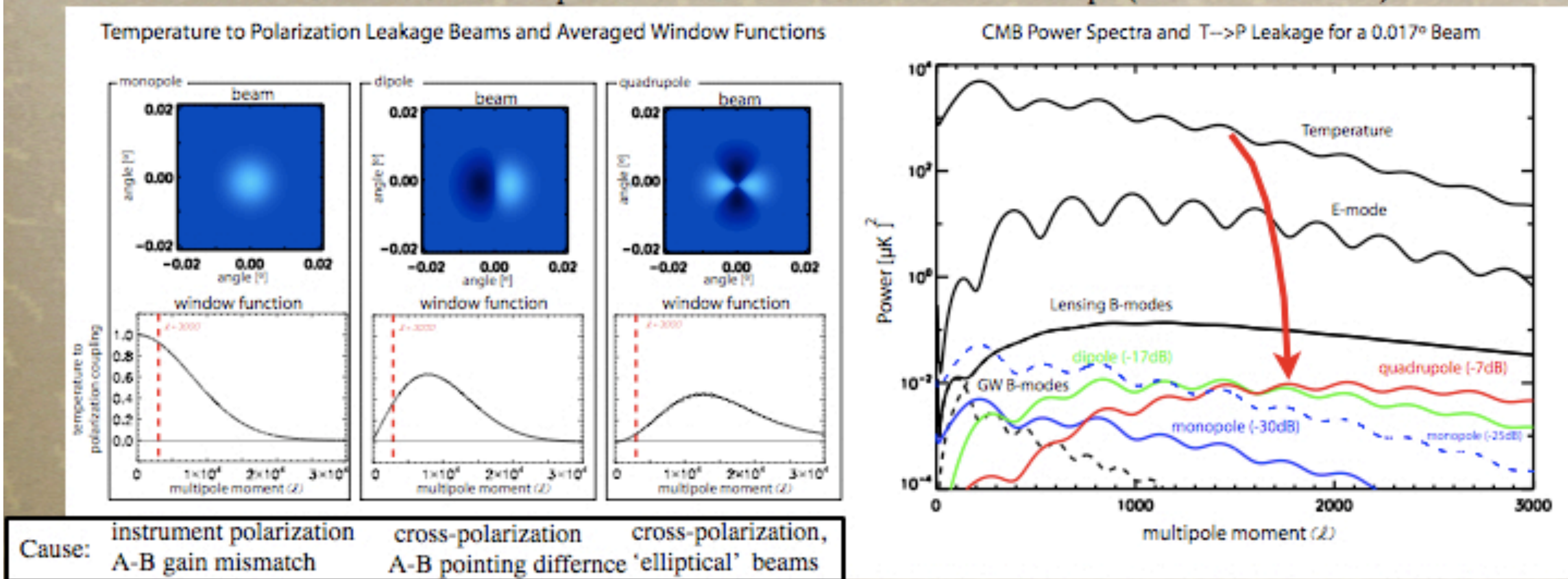

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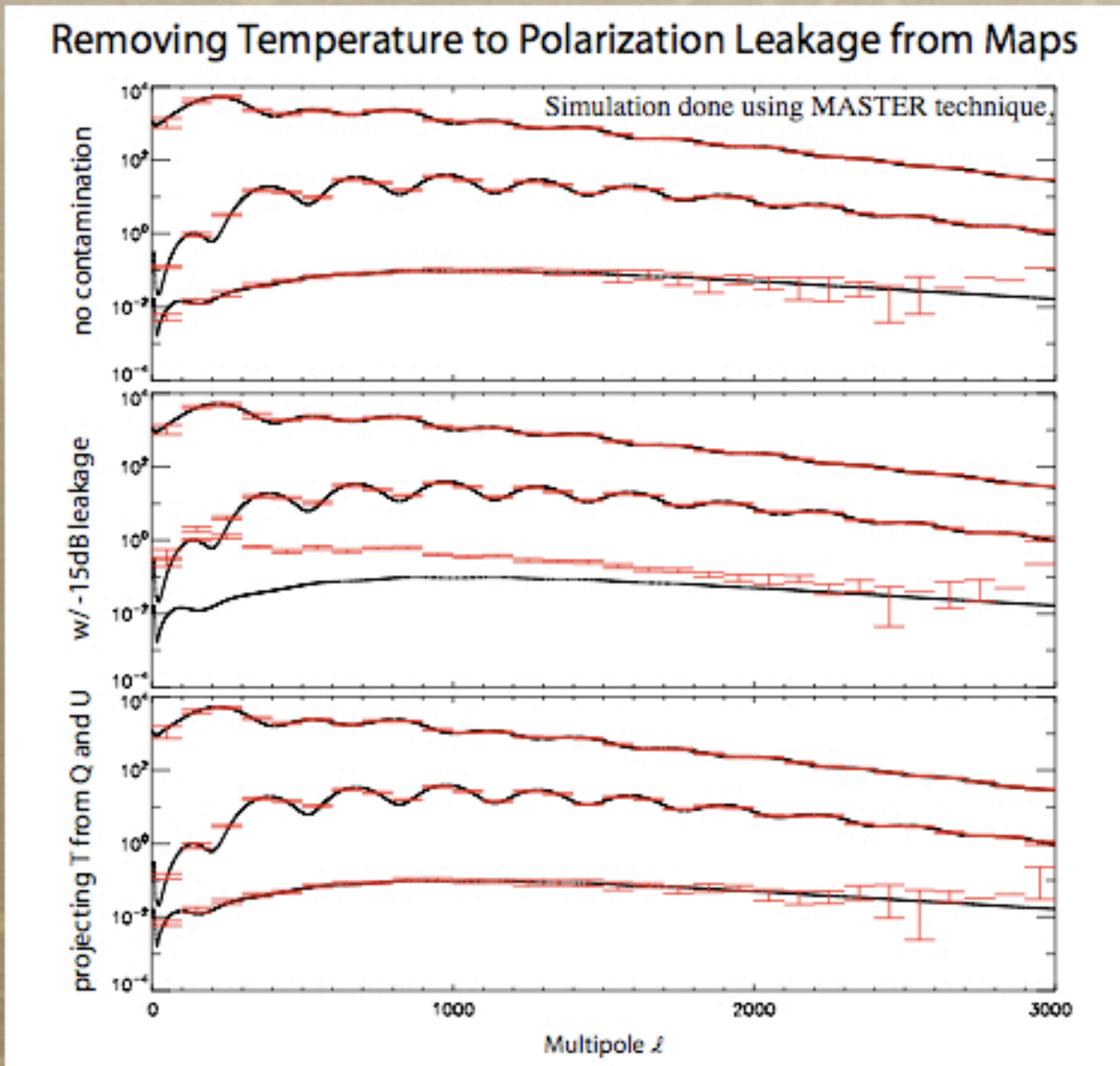
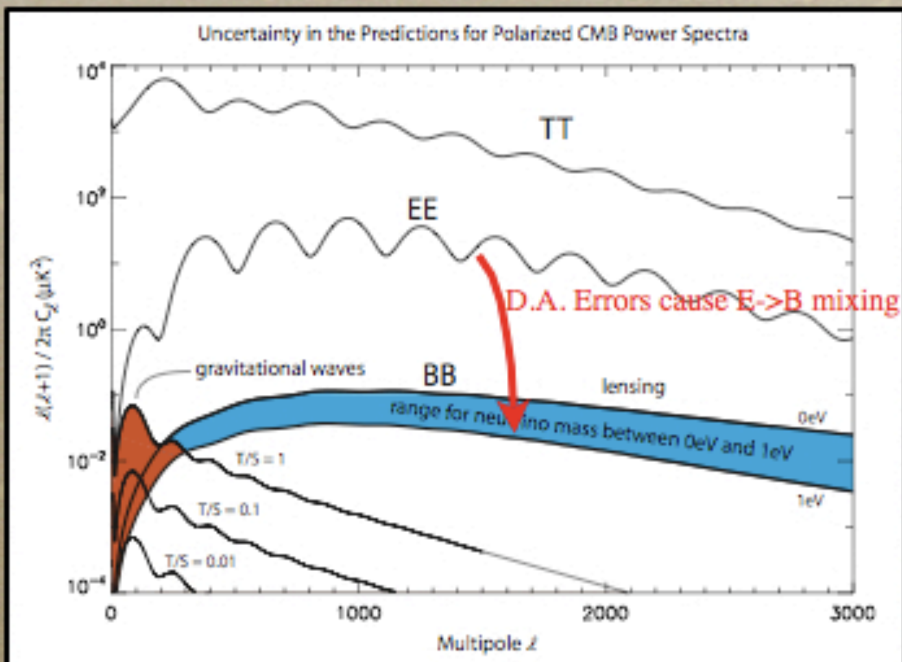
I->Q/U mixing can be cleaned



- Plan of attack:
  project measured T map (convolved with leakage beam) from the measured Q and U maps
- Calculation done for monopole only (should apply to higher order terms)
- -15dB monopole leakage is very pessimistic
- Requires high fidelity map of T preferably with the same instrument
- This technique can surely be extended to dipole, quadrupole + higher order leakages.

Detector Angle Calibration

Calibration Requirement



Errors in the detector angles mix E and B in the same way as Q and U are mixed

$$\begin{bmatrix} E_m \\ B_m \end{bmatrix} = \begin{bmatrix} \cos 2\theta_e & -\sin 2\theta_e \\ \sin 2\theta_e & \cos 2\theta_e \end{bmatrix} \begin{bmatrix} E \\ B \end{bmatrix}$$

E is about 100 times larger than B (in thermal units)
=> need to control to 1 / 1000 => **0.5° cal. requirement**

Approaches to **Detector Angle** Calibration

- Moon
  CAPMAP achieved ± 2° accuracy
  statistical errors much better, limited by model
  improved model could yield sub degree accuracy
  saturation is an issue: (Add high G detectors)

- Astronomical sources
  Cen A w/ ATCA @ 90 GHz?

- Terrestrial Sources (Towers)
  high signal to noise
  requires refocusing, not on sky
  great for relative calibration

- **Use the EB spectrum!** +rel cal from tower

Detector Angle Calibration

Using the EB spectrum to calibrate detector angle

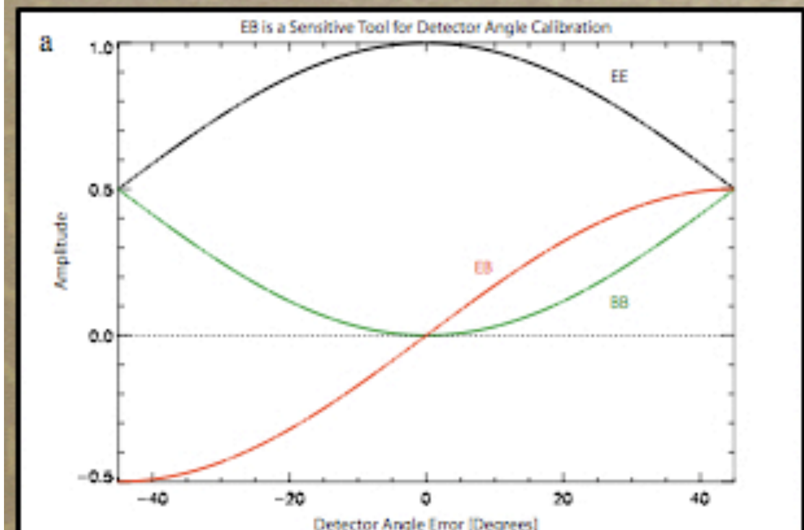
Idea from Kendrick Smith

from theory: <EB> = 0

(assuming no foregrounds)

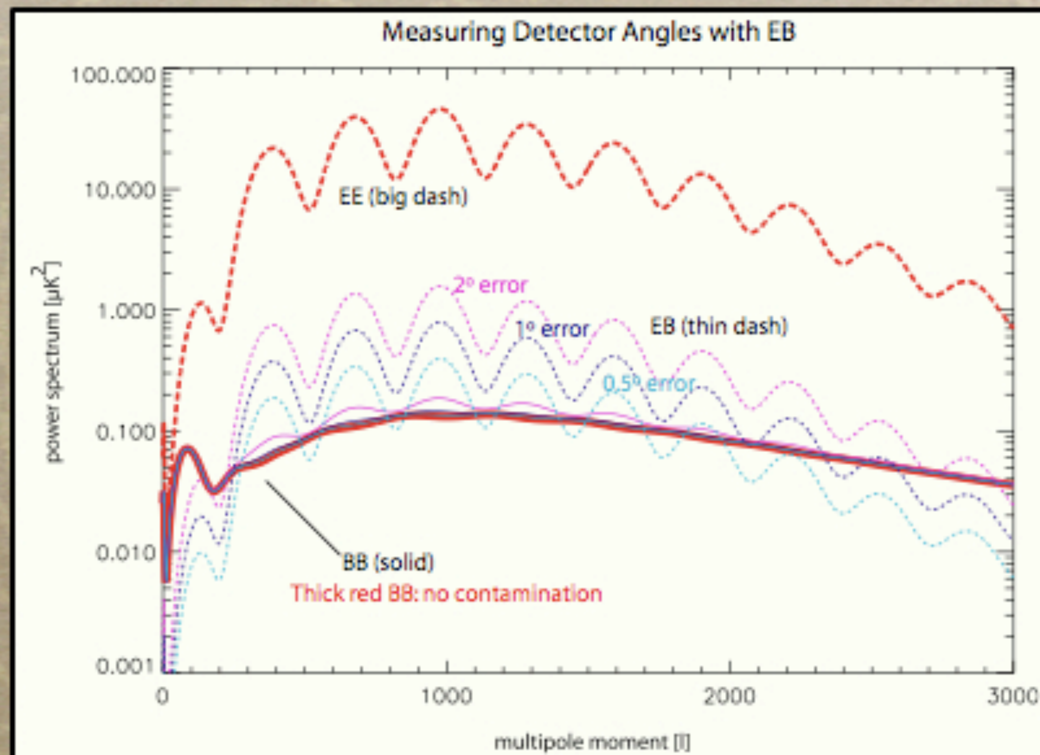
paralactic angle errors cause mixing and a non-zero <EB>

$$< EB >_m = < EE > \cos(\theta_\epsilon) \sin(\theta_\epsilon)$$



Note: the EB spectrum is more sensitive to this effect than BB since the mixing is first order

$$< BB >_m = < BB > \cos^2(\theta_\epsilon) + < EE > \sin^2(\theta_\epsilon)$$



*Lensing increases the variance of <EB> but does not change the mean.

Conclusion

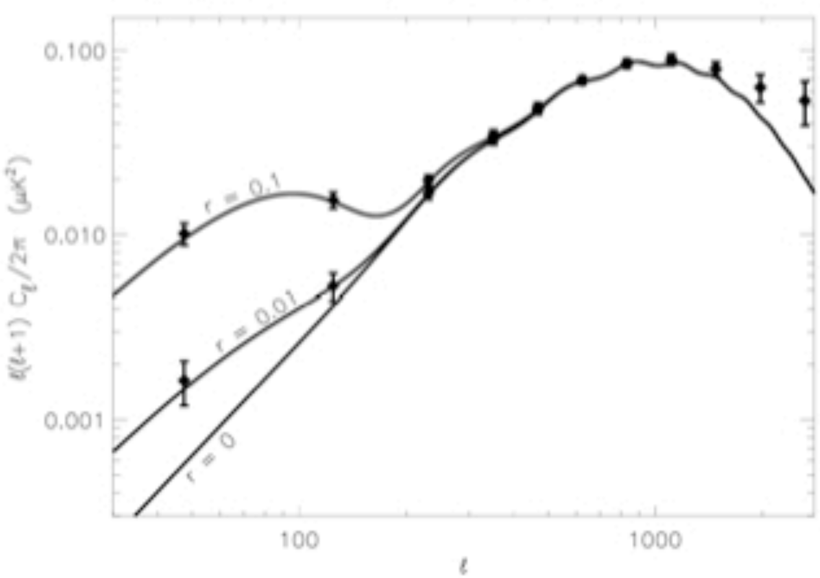
Systematics Summary:

- Ground Pickup is already small + scan strategy will moderate this effect
- Measure far side-lobes and eliminate any possible sensitivity to the galaxy
- Small beam suppresses I->P dipole and quadrupole
- E->B mixing from cross-polarization is small
- Can use measurements of T to check for (or clean) I->P leakages
- EB provides a check on detector angles

Outlook:

- SPTpol will do a great job with Lensing
- SPTpol will measure r to 0.01 (provided we can control ground pickup + 1/f)

B-mode Projection



$\sigma(r) = 0.004$

Simulation inputs:

1000 bolometer pairs

3 years / 50% efficiency

Simulation includes:

1/f noise

point sources

foregrounds + cleaning

E/B separation

projection of monopole

removal of DC on each scan