

# Observations of the Temperature and Polarization Anisotropies with Boomerang 2003

William Jones

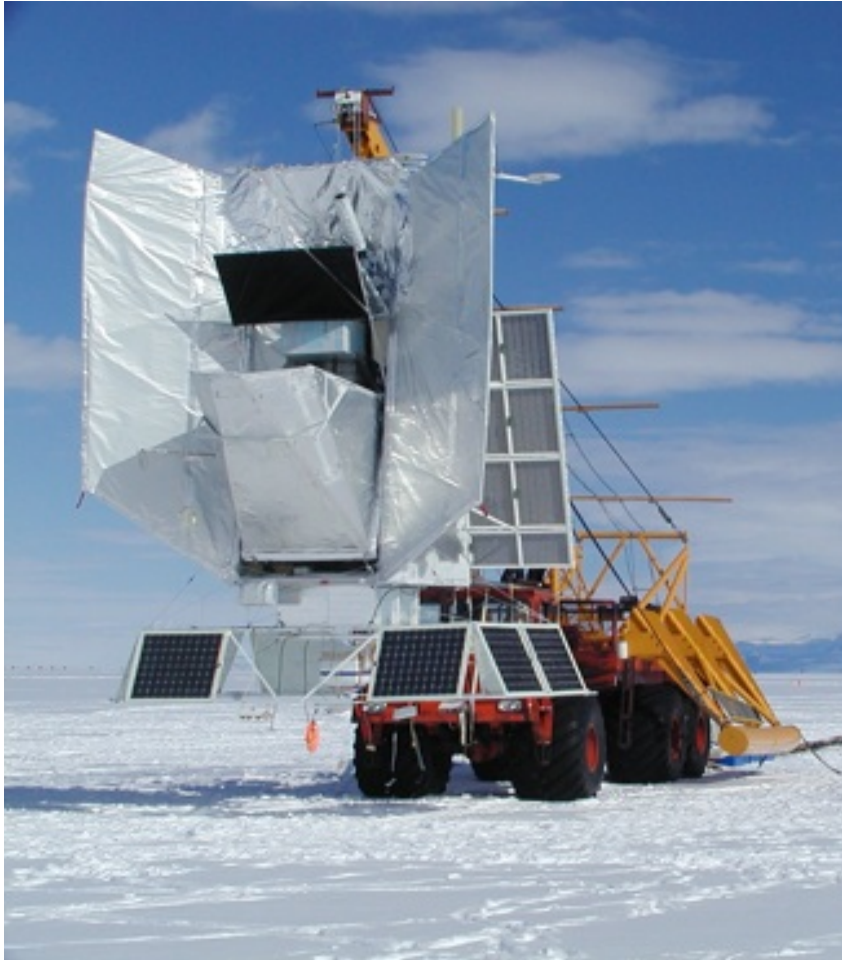
Caltech/JPL

Observational Cosmology

Inflation Probe Systematics Workshop

Annapolis, MD July 28-30

# Boomerang 2003



## The BOOMERANG Collaboration

California Institute of Technology V. V. Hristov, W. C. Jones, A. E. Lange

Case Western Reserve University T. Kisner, T. Montroy, J. Ruhl

University of Toronto C. MacTavish, C. B. Netterfield, E. Pascale

Universita' di Roma La Sapienza P. de Bernardis, S. Masi, F. Piacentini,  
G. Polenta, A. Iacoangeli

IPAC B. P. Crill, K. Ganga, E. Hivon

CITA D. Bond, C. Contaldi

JPL J. J. Bock

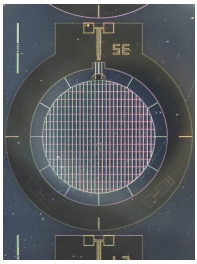
Cardiff University P. Ade, P. Mouskops

IROE A. Boscaleri

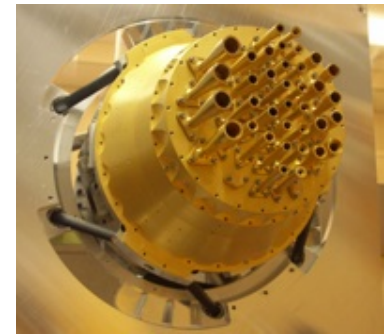
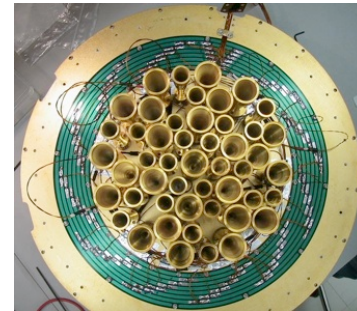
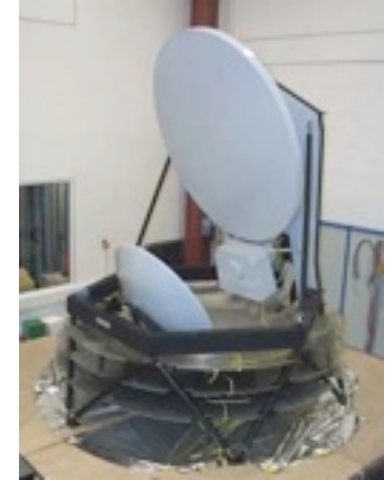
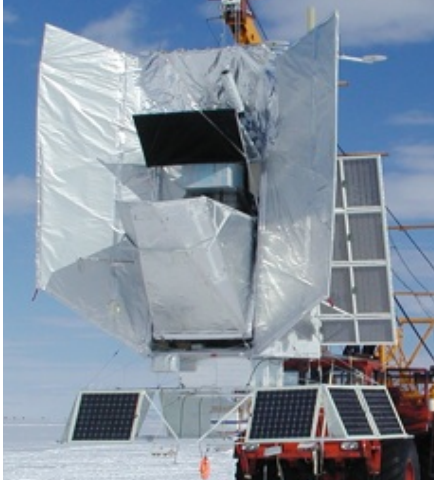
ING G. Romeo, G. di Stefano

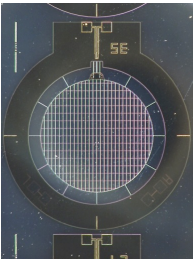
LBL, UC Berkeley J. Borrill

<http://boom.caltech.edu>



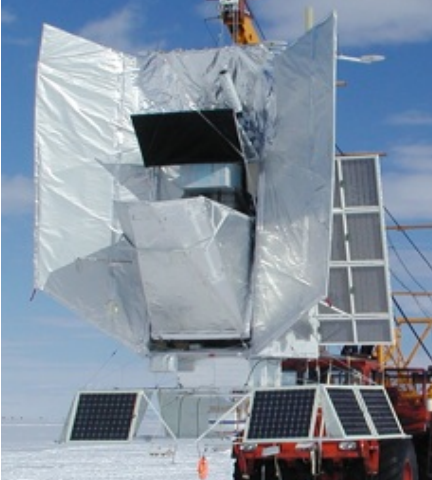
# Polarization Sensitive Bolometers: Enabling 3 generations of experiments





# Polarization Sensitive Bolometers: Enabling 3 generations of experiments

**Boomerang03**



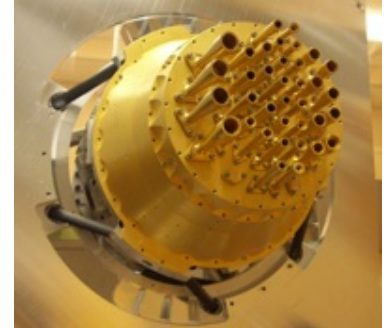
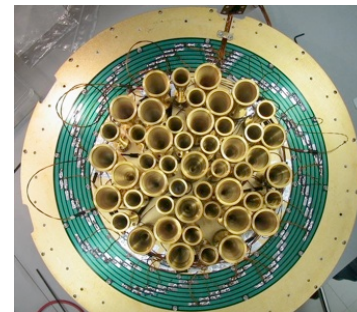
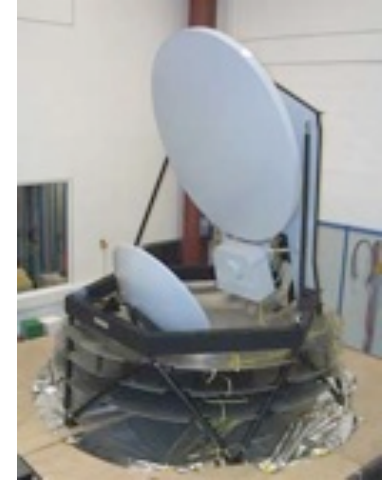
**QUaD<sup>1</sup>**



**Robinson Telescope<sup>2</sup>**



**Planck HFI<sup>3</sup>**

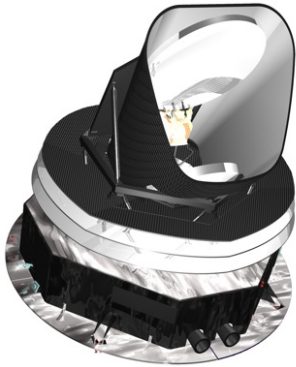


**[astro-ph/0206254](https://arxiv.org/abs/astro-ph/0206254) and [astro-ph/0606606](https://arxiv.org/abs/astro-ph/0606606)**

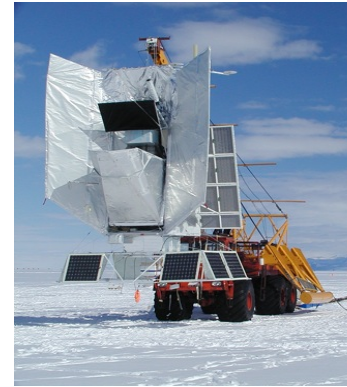
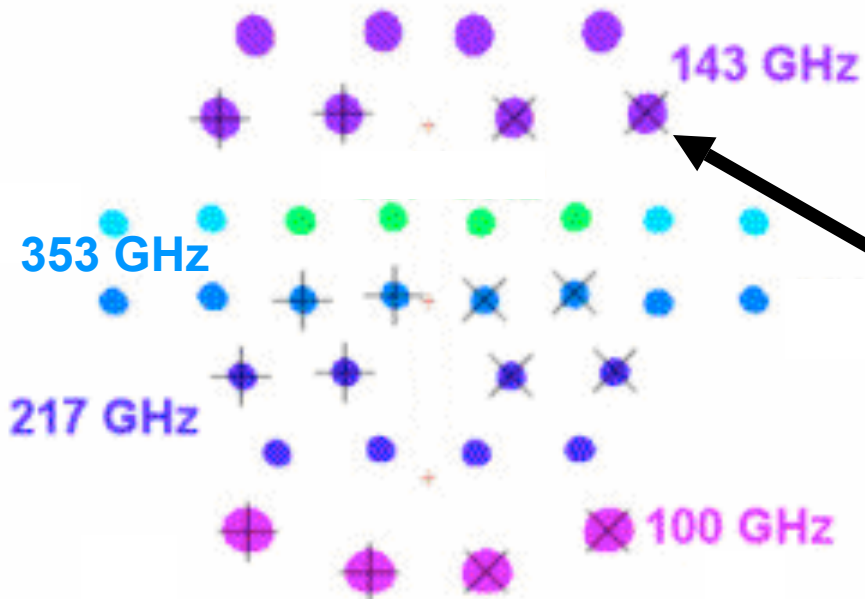
**<sup>1</sup> Clem Pryke's talk this afternoon**

**<sup>2</sup> John Kovac's talk also this afternoon**

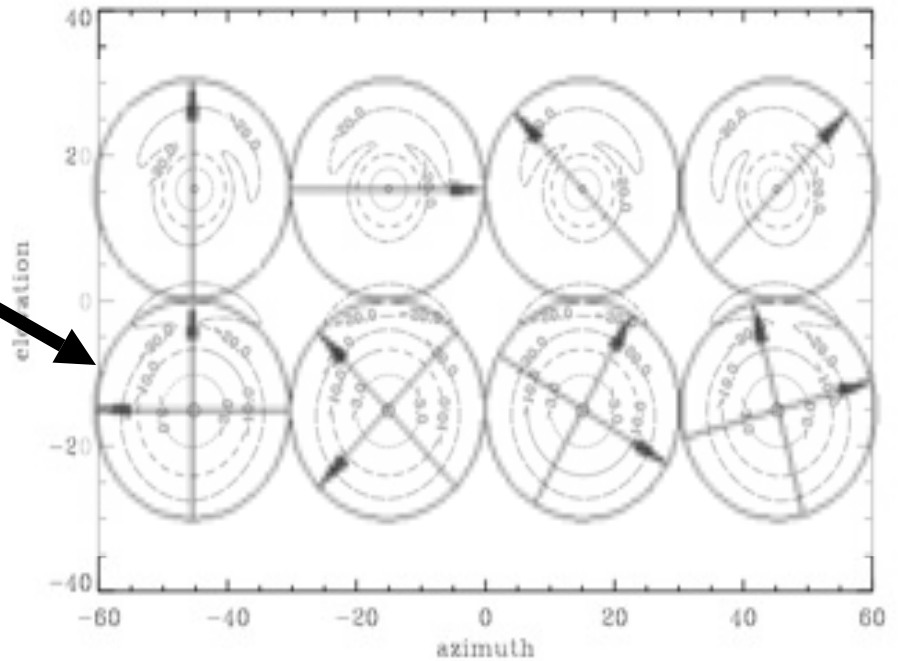
**<sup>3</sup> Kris Gorski's talk tomorrow**

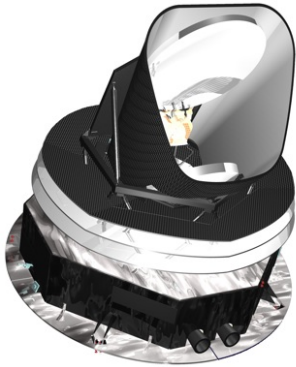


**Planck HFI**

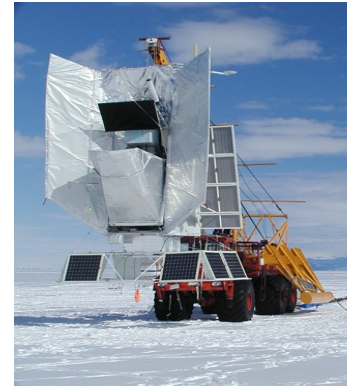
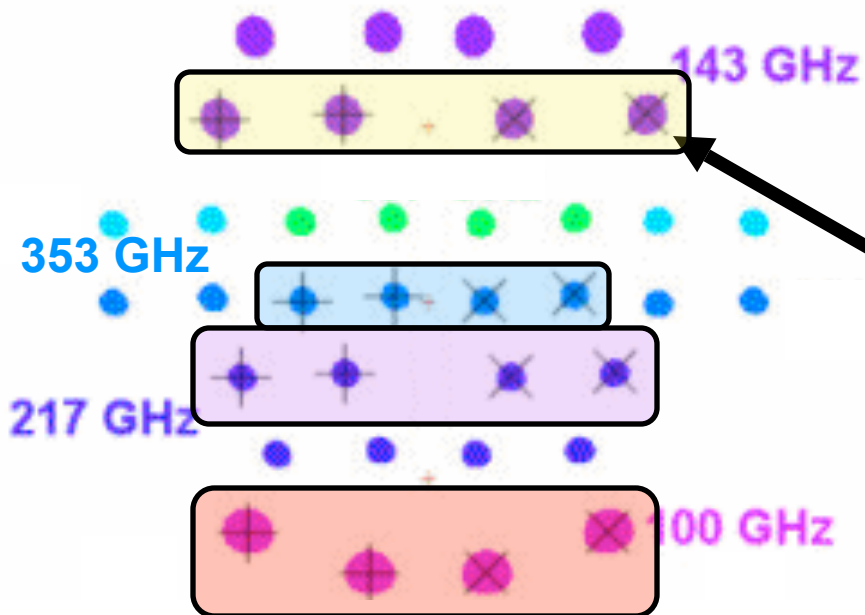


**Boomerang 2003**

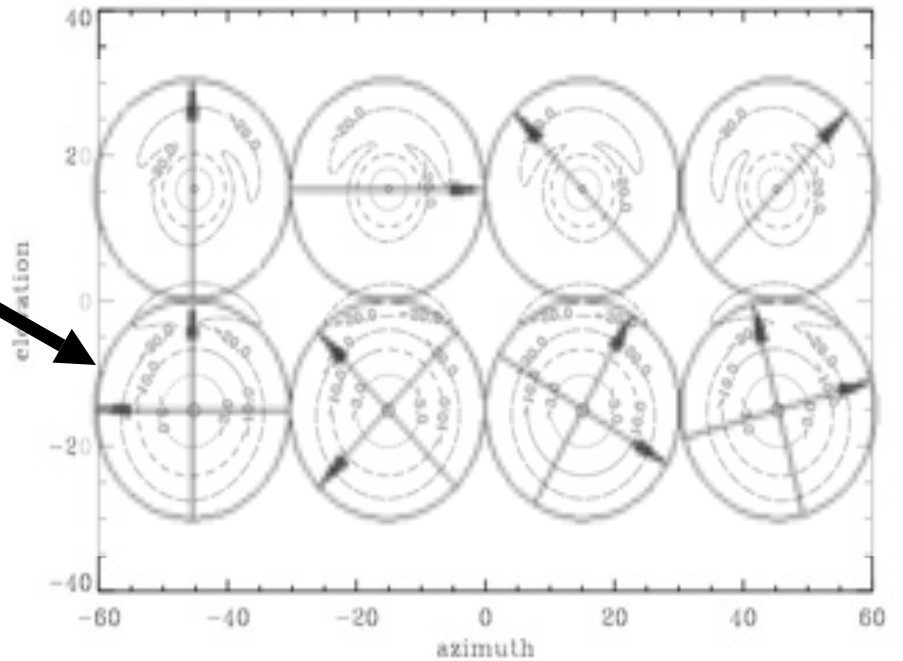




**Planck HFI**



**Boomerang 2003**



# Boomerang 2003: Experiment Details

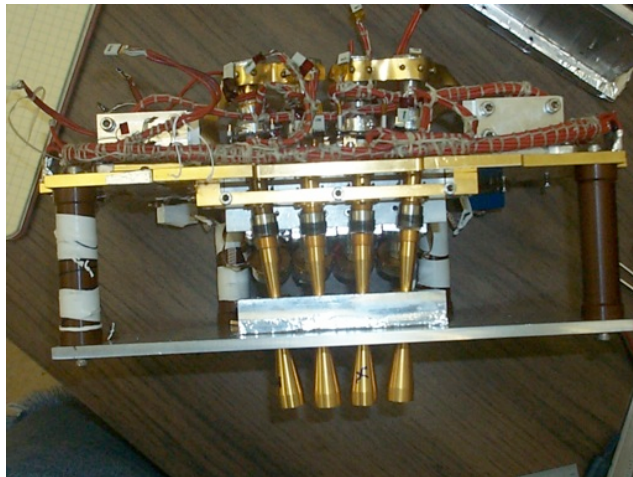
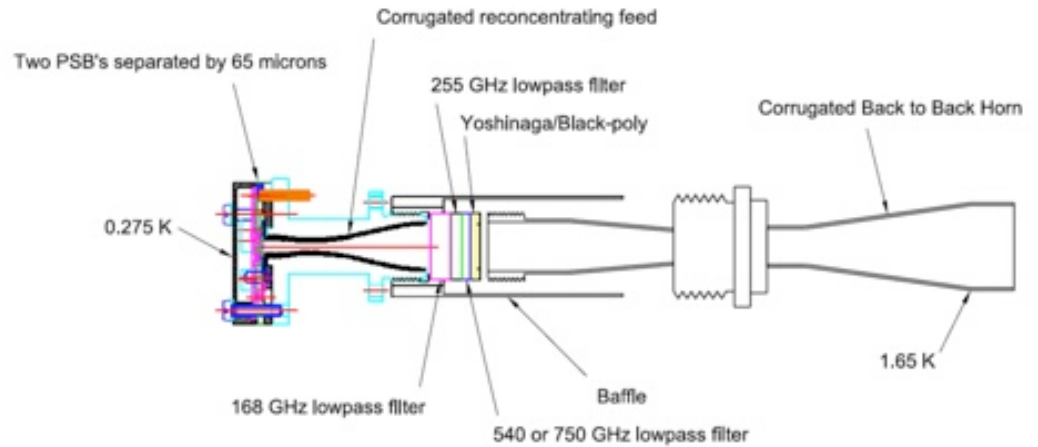
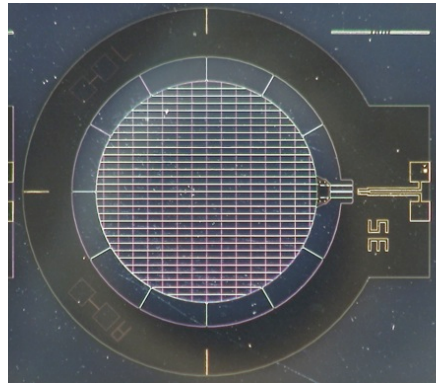
Angular resolution	11 / 7 / 7	Arcminutes
Frequency Coverage	145 / 245 / 345	GHz
Sky Coverage	1.84 % (0.22 %)	760 Square Degrees
Multipole Coverage	75 - 1400	-
Polarization Modulation?	none	-
Types of Detectors	PSBs / grids / grids	-
Location	Balloon	-
Instrument <b>NET</b>	63 / 161 / 233	$\mu\text{K s}^{1/2}$
Limit on $r$	$< 0.36$ (BB $<8.6 \mu\text{K}^2$ )	-
Status	Final Flight: 2002/3	-

# Boomerang 2003: Instrument and Observing Strategy

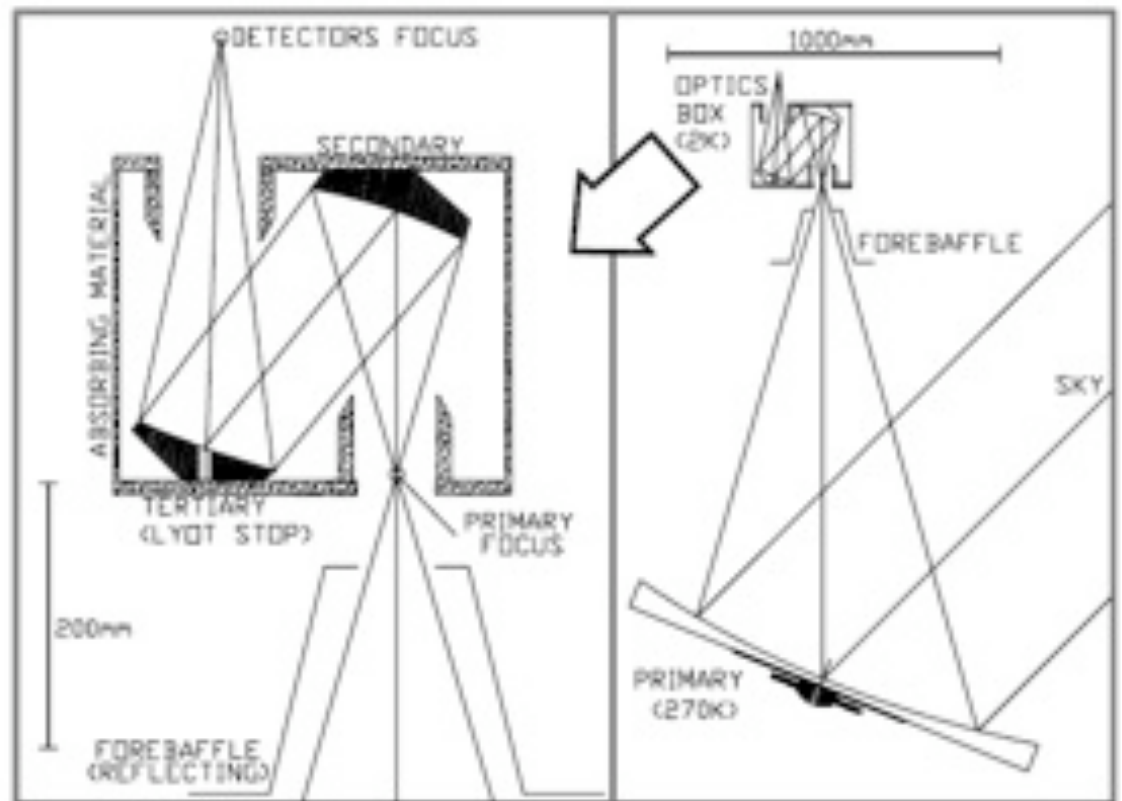
- Optics : Off--axis Gregorian w/Dragone-ish conditions
- Band definitions : Resonant mesh filters
- Polarization selection : Polarization Sensitive Bolometers
- Polarization modulation : Sky rotation and scan strategy
- Scan strategy : Constant elevation scans
- Pointing reconstruction (accuracy) : 2.5-ish arcminutes



# 145 GHz PSB Pixel



Boomerang 2003  
Focal Plane



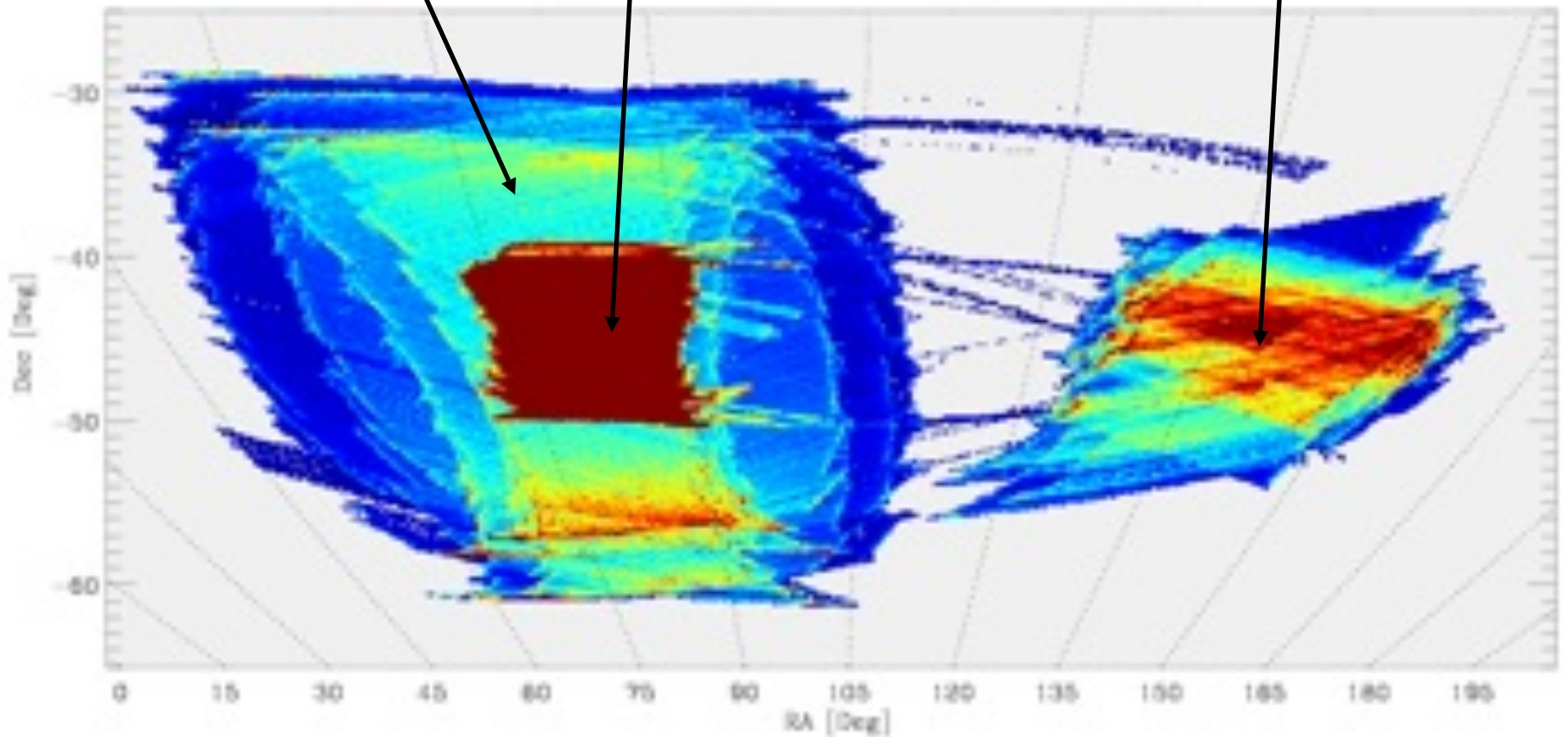
# January 2003: Sky Coverage

120 hours

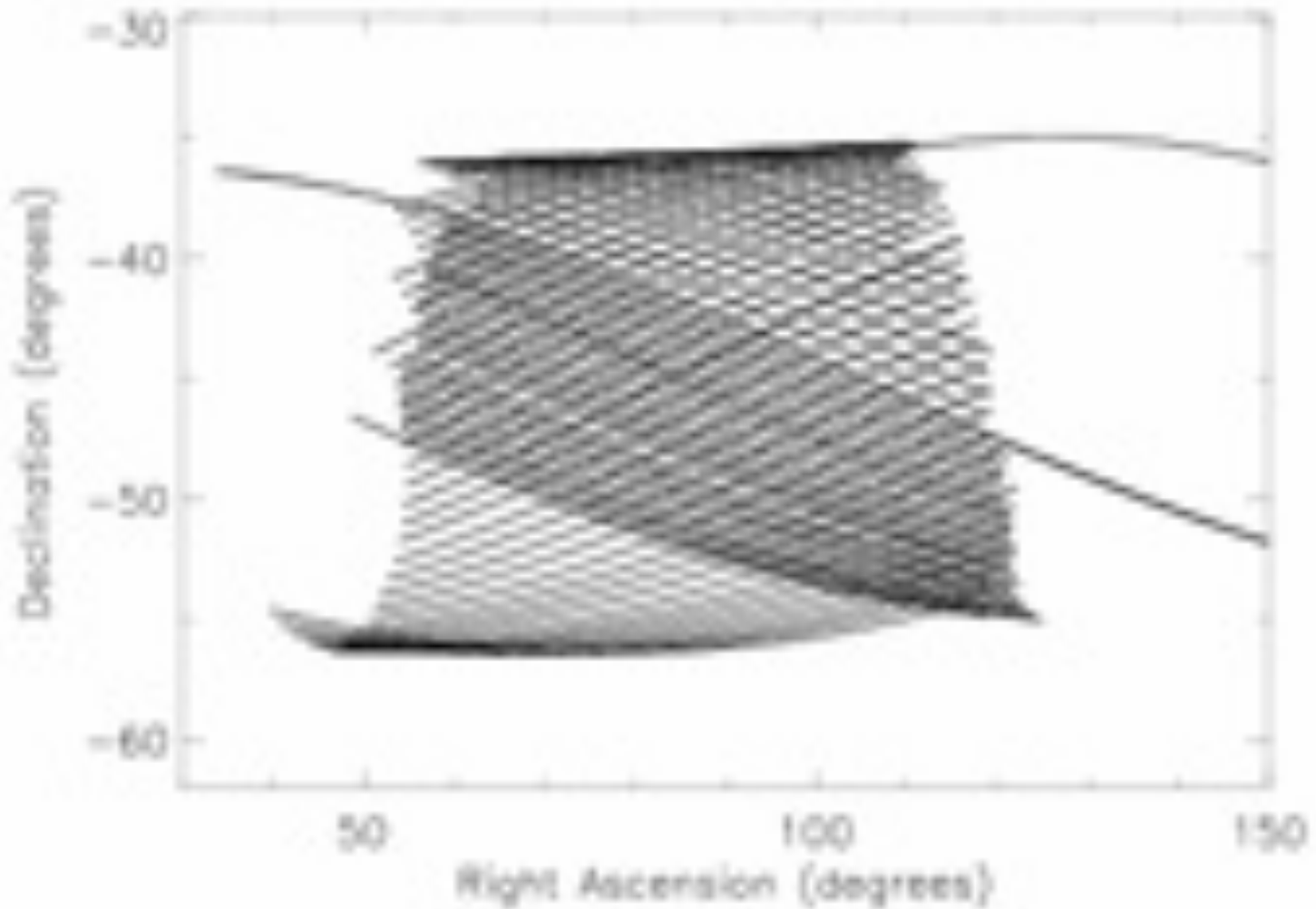
75 hours

30 hours

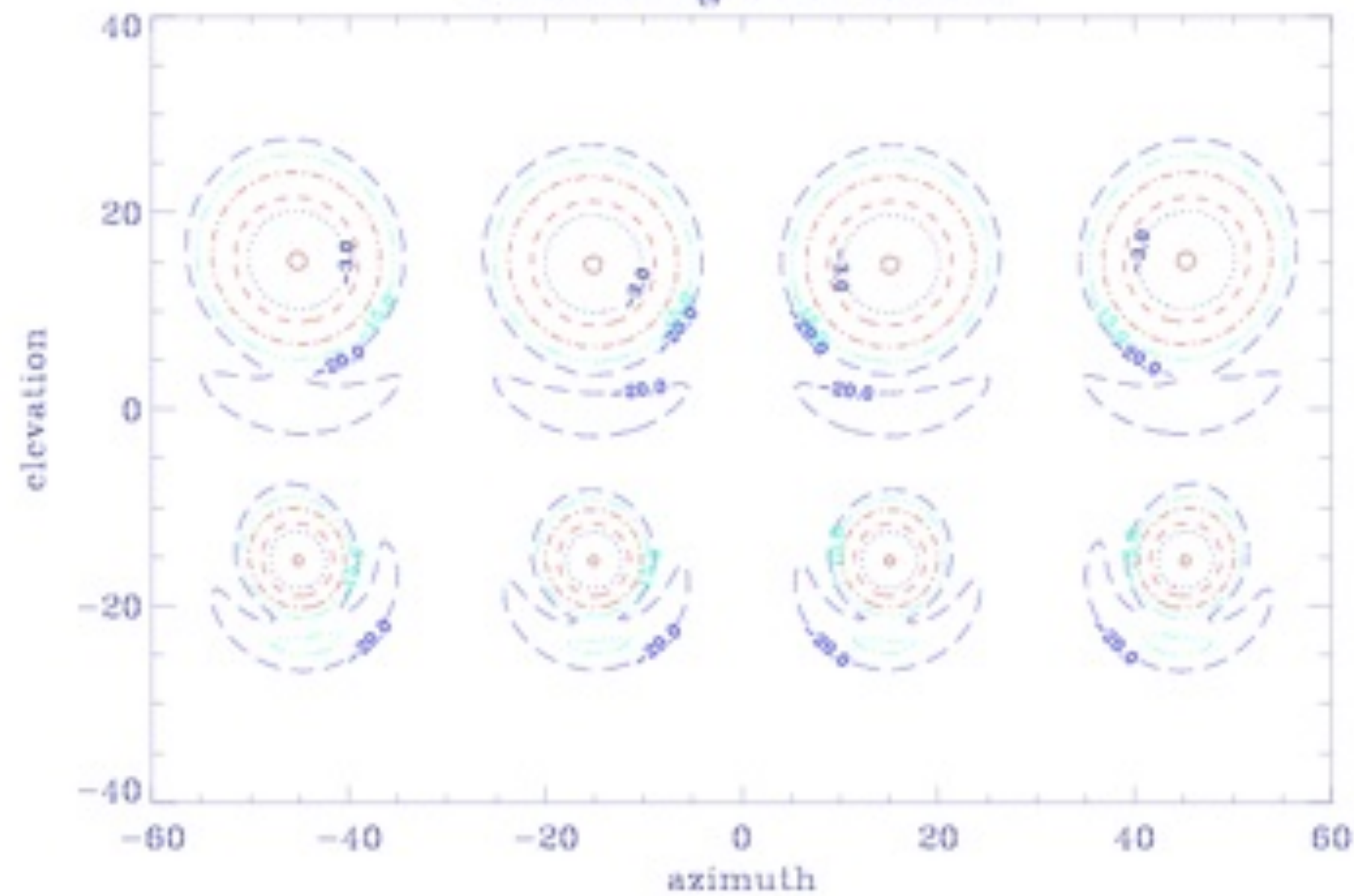
B2K Coverage



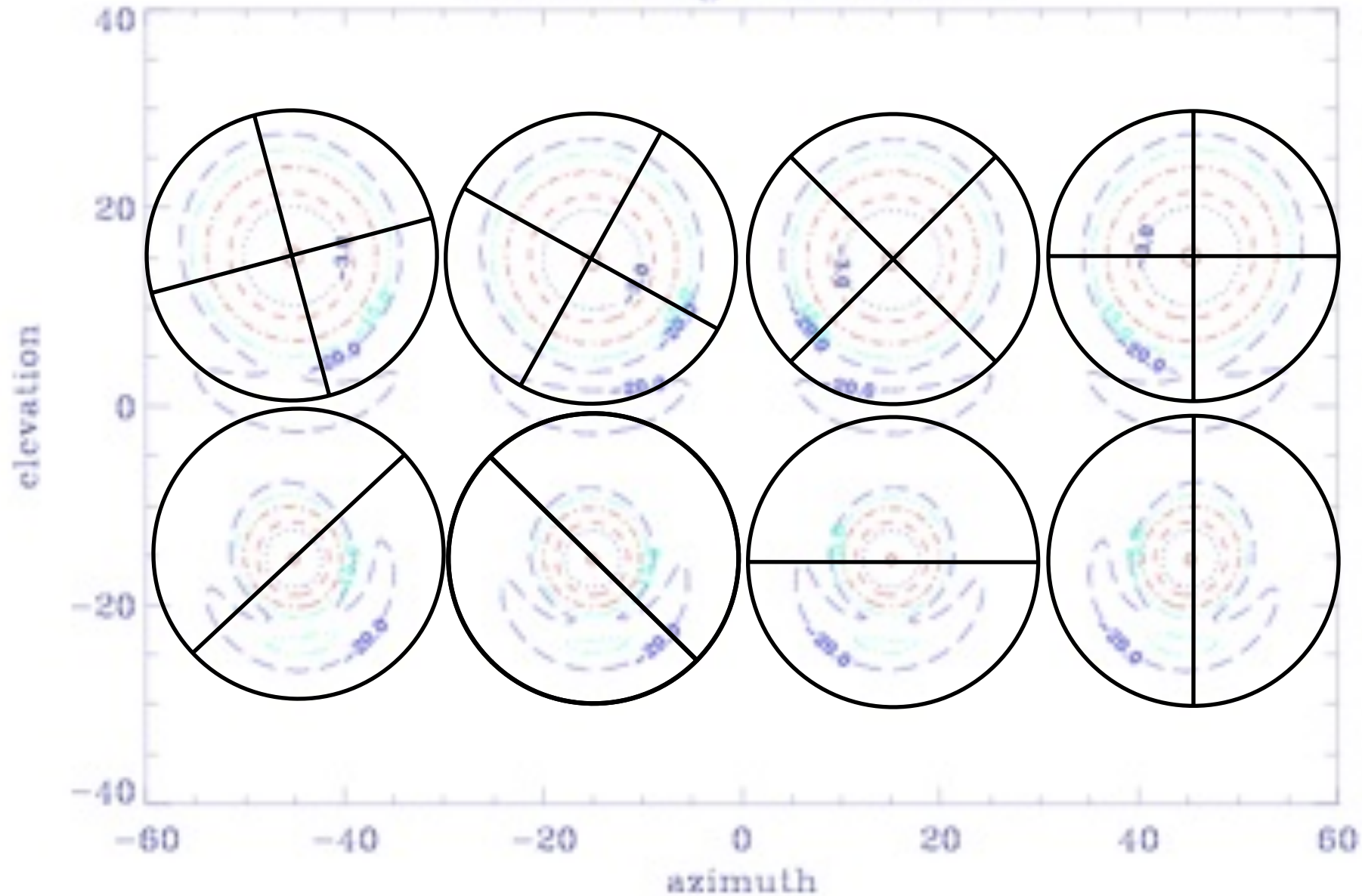
Sky Rotation: The world's best polarization modulator!  
(if only it wasn't so darn slow...)



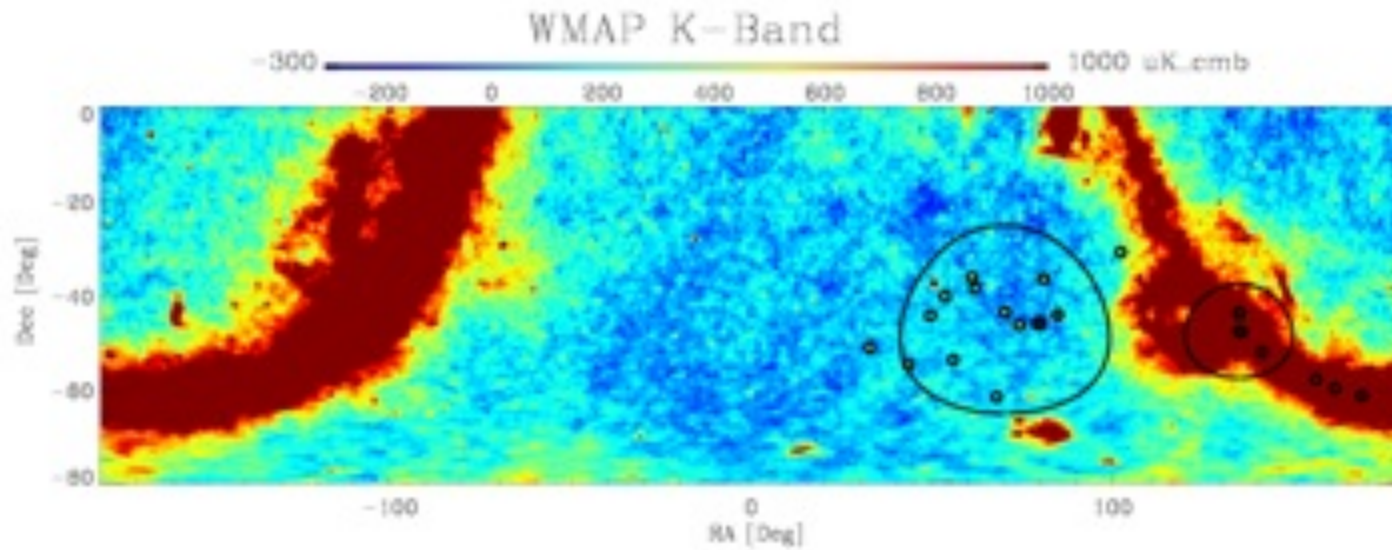
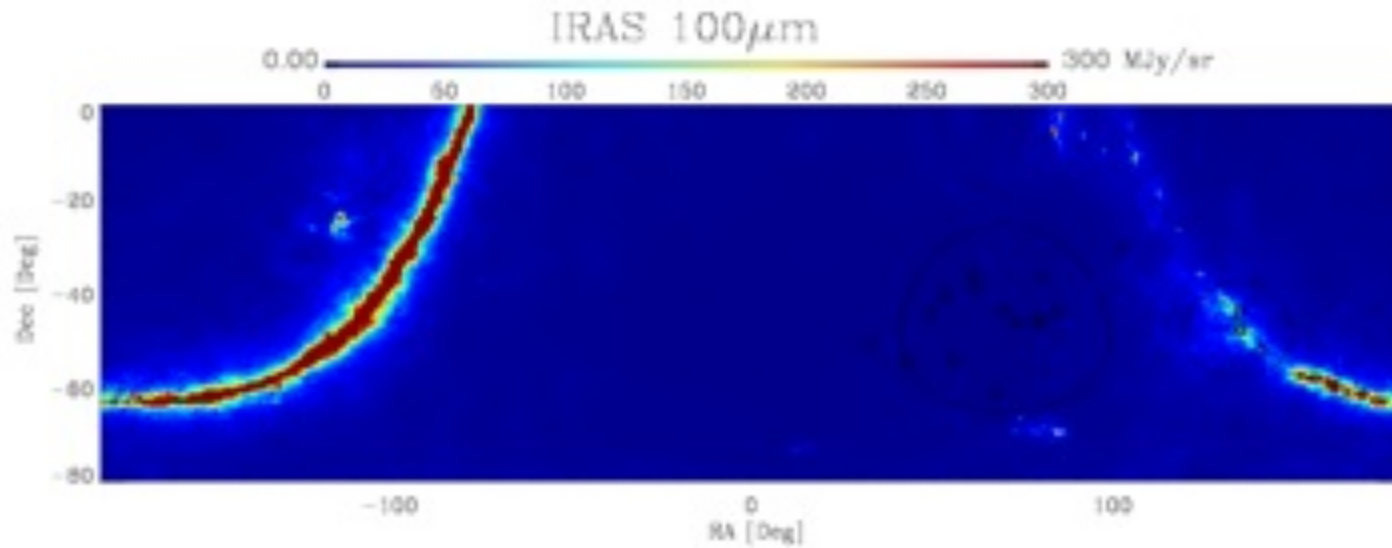
# Boomerang 2002 Beams



# Boomerang 2002 Beams



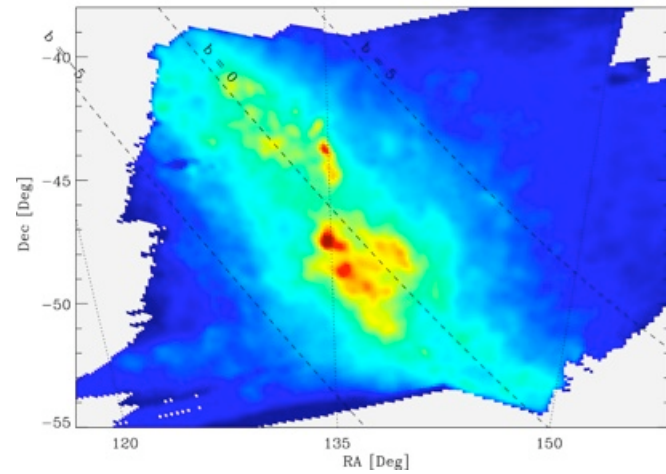
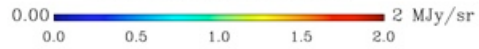
# January 2003: Sky Coverage



# Boomerang Galactic Plane Survey

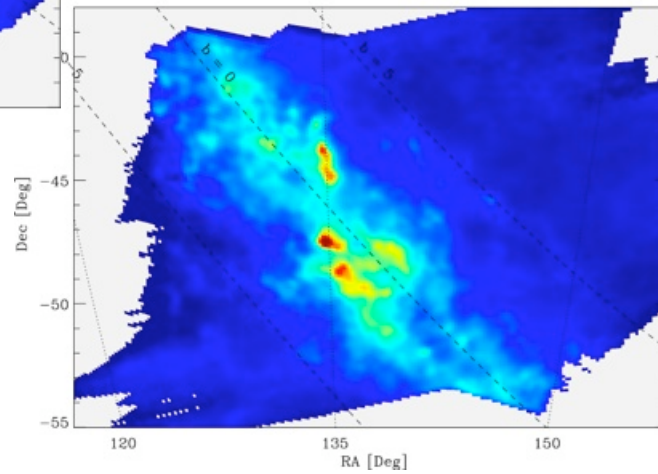
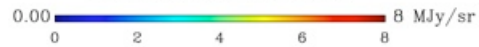
## 150 GHz

Boomerang03 145 GHz



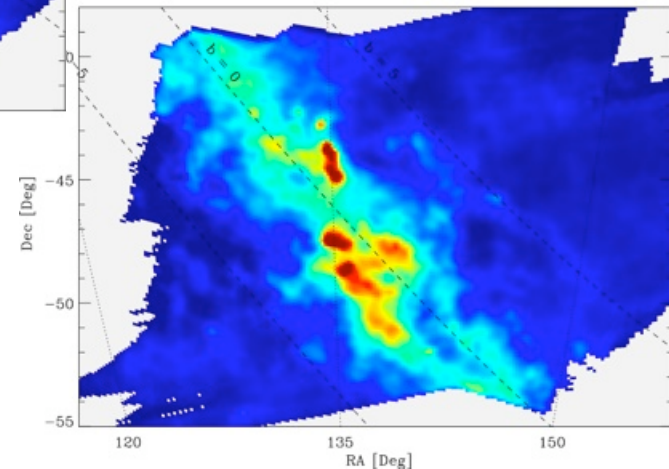
## 245 GHz

Boomerang03 245 GHz



## 345 GHz

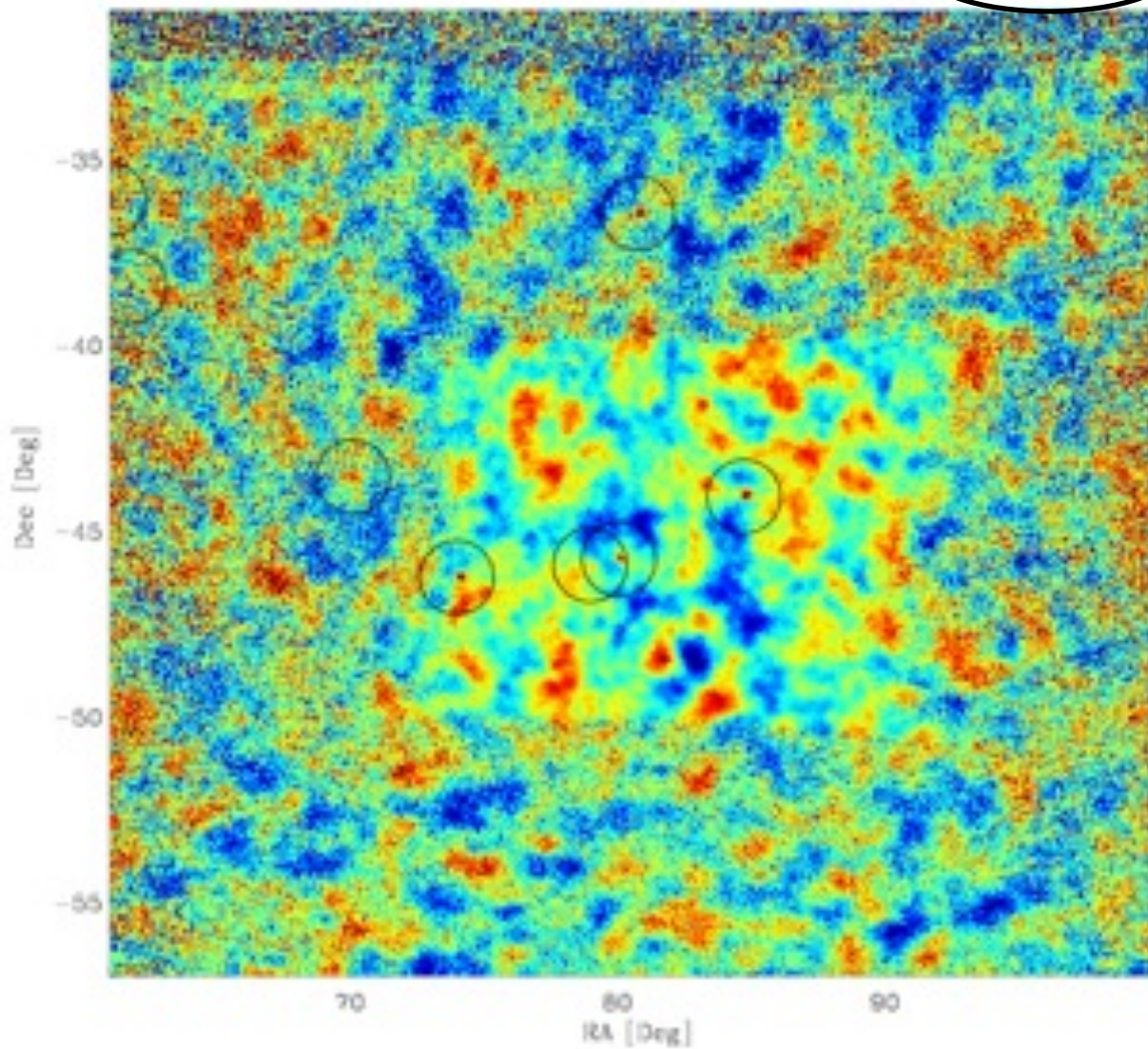
Boomerang03 345 GHz



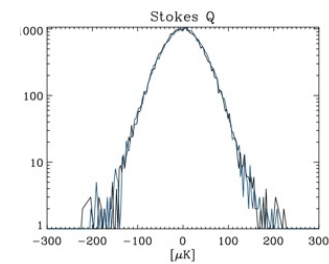
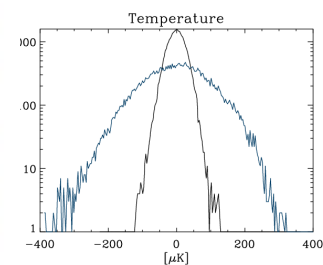
# Boomerang 2003 145GHz



3.4' pixels

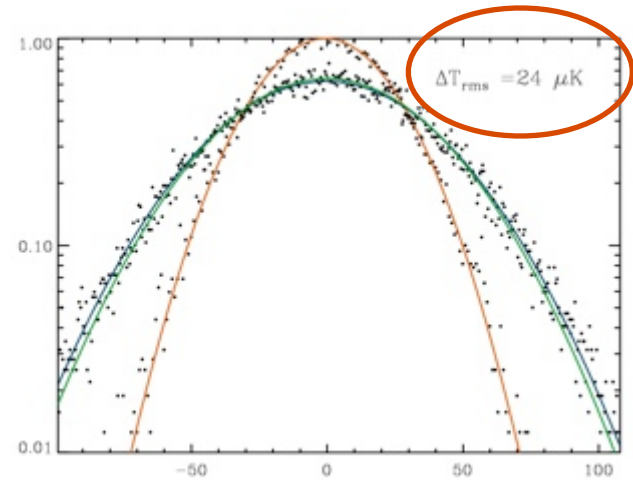
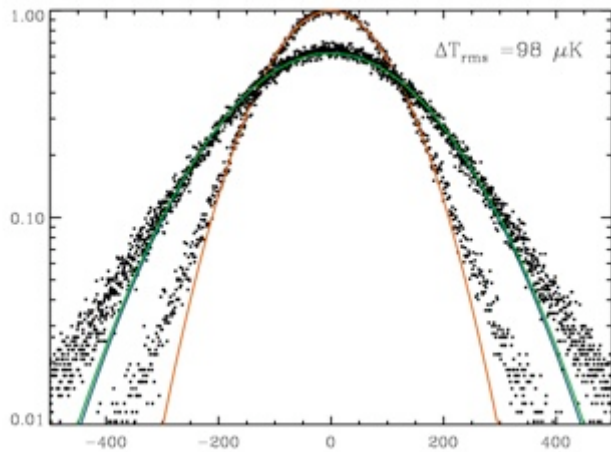
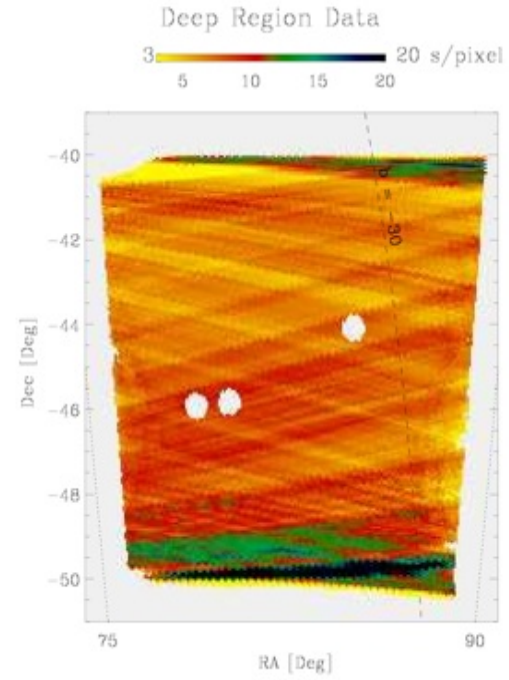
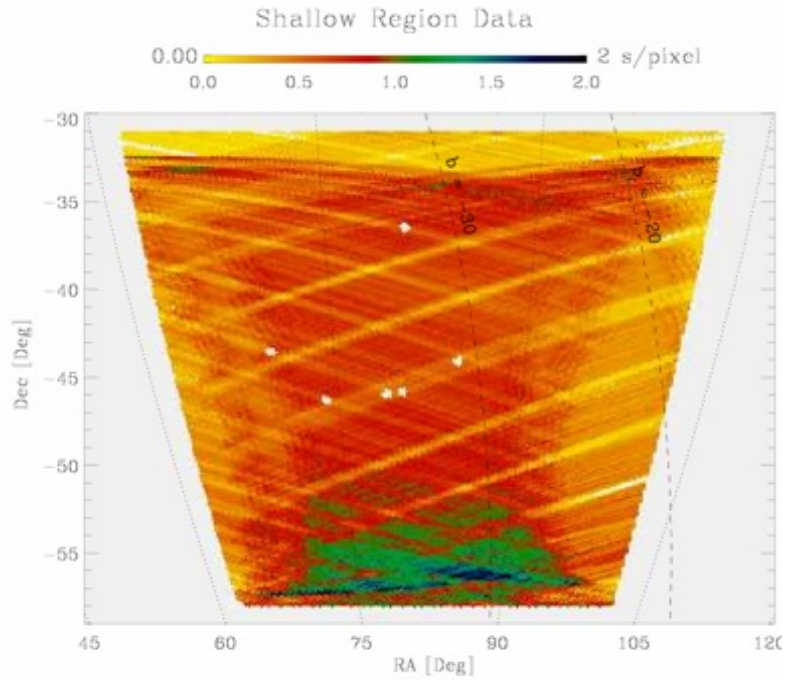


## Sum and difference histograms

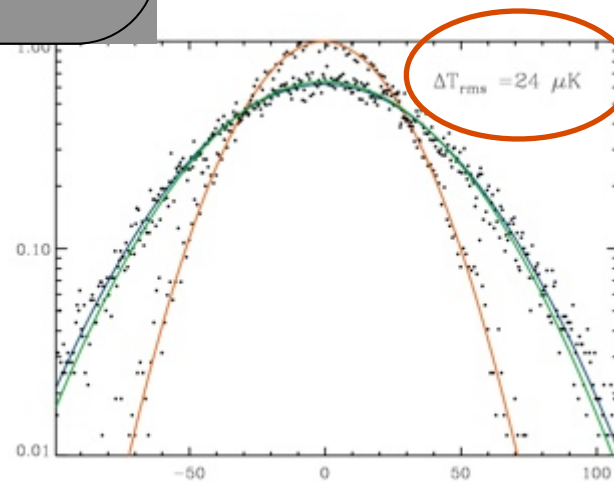
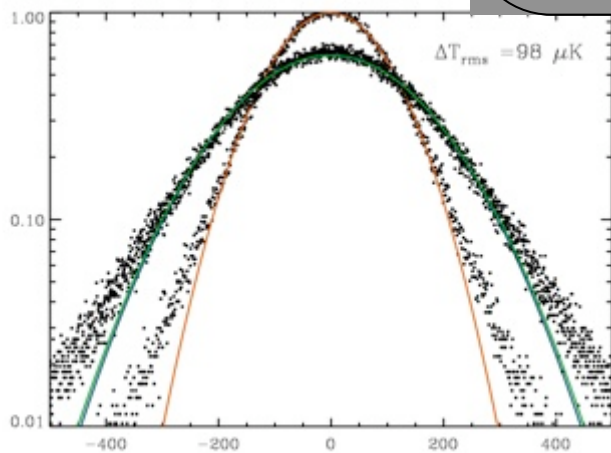
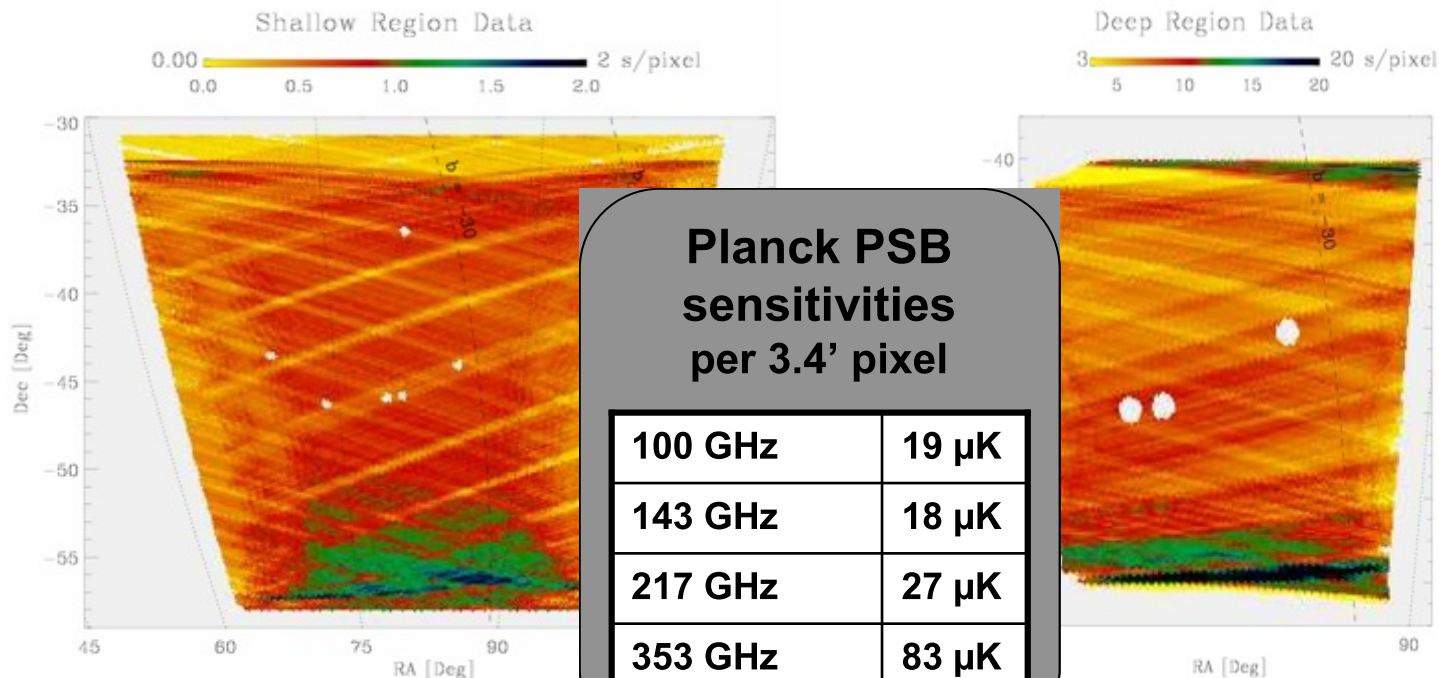




# Boomerang 2003: sensitivity per 3.4' pixel



# Boomerang 2003: sensitivity per 3.4' pixel



# Boomerang 2003: Issues/Lessons/Concerns

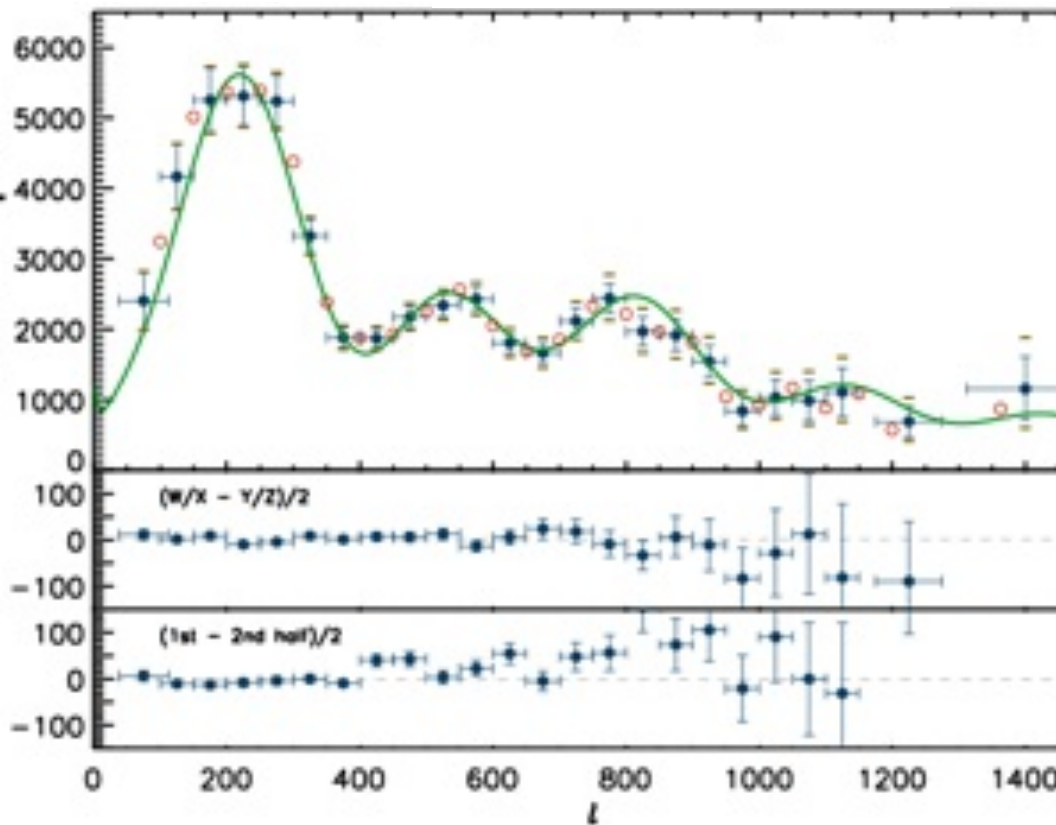
- A well **cross-linked map** is critical for high fidelity polarimetry
  - Both scan strategy and polarization modulation (**sky rotation/scan**)
- Knowledge of **absolute polarization angles**
  - Overall focal plane offset (**preflight measurements**)
- Understanding the solid angle of the  $< \sim 30$  dB sidelobes
  - Required for extrapolating calibration to other scales (**beam maps**)
- Unbiased **noise model**
  - Power spectra bias / failure of consistency tests (**lots of simulations**)
- Knowledge of relative calibrations
  - Can generate spurious polarization (**derived from cmb/calibration lamp**)
- Characterization/stability of the **detector transfer functions**
  - Can generate spurious polarization (**not well characterized in flight**)
- Beam shapes not significant: science well below beamscale

# Boomerang 2003: Consistency Tests

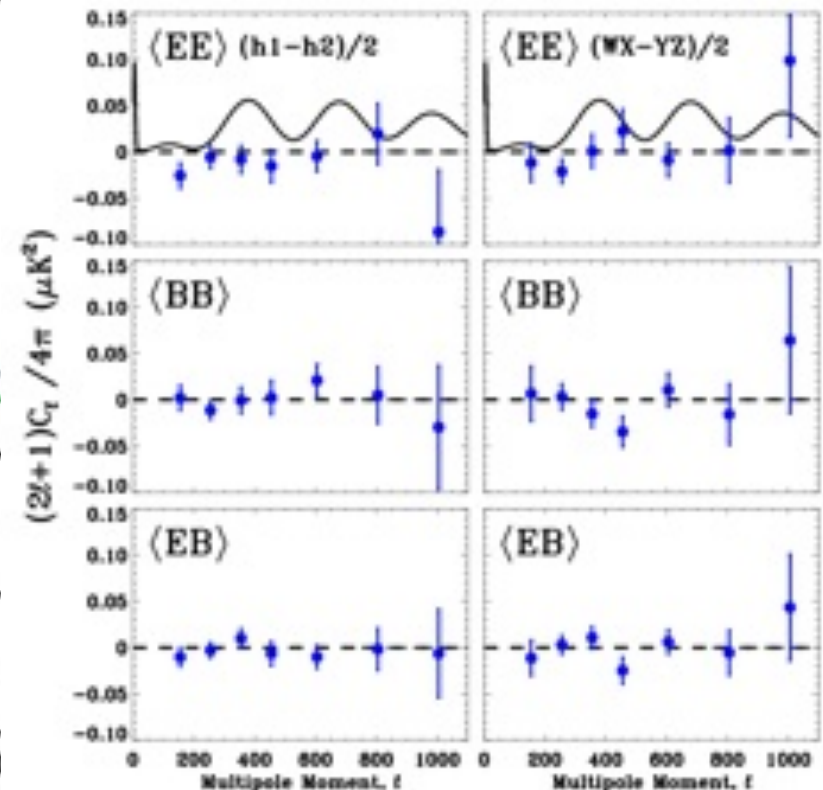
At the noise per pixel of B03 (and therefore  $\sim$  Planck) we are not limited by:

- Instrumental systematics
- Environmental systematics (eg atmosphere)

## Unpolarized Intensity

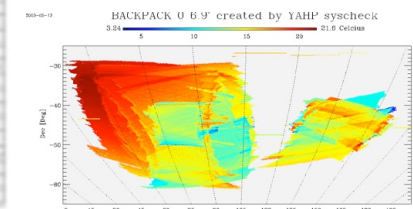
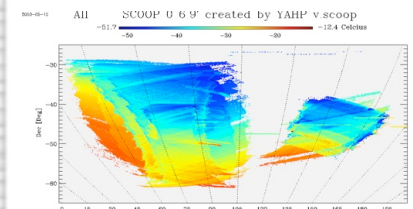
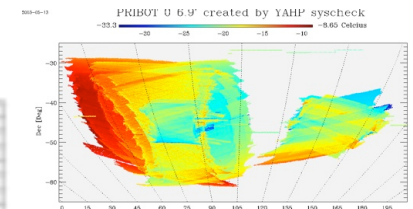
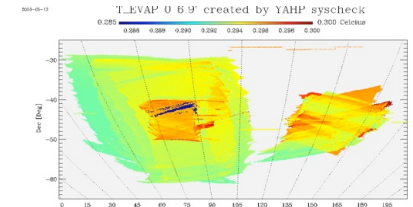
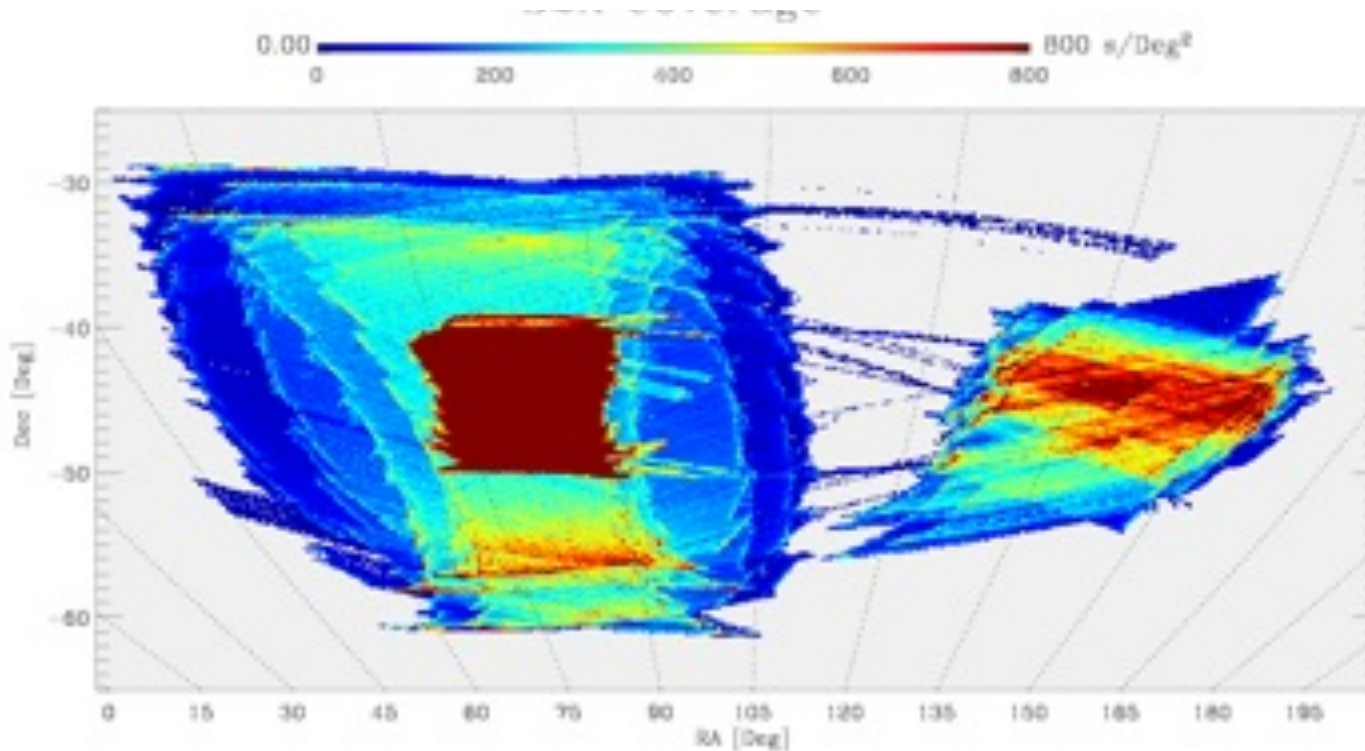


## Polarized Intensity



# Crosslinking: decoupling instrumental systematics from the signal on the sky

Pointing reconstruction, system temperatures, RFI, microphonics, beam asymmetries, instrumental polarization, etc...



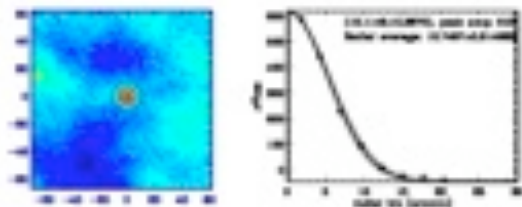


Figure 3.9: (PKS)0537-441, no background subtraction

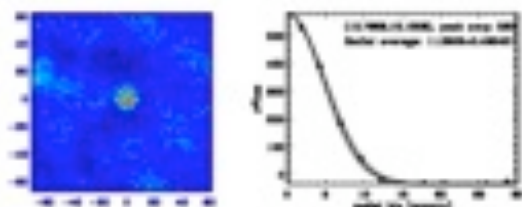


Figure 3.10: (PKS)0537-441, using background subtraction

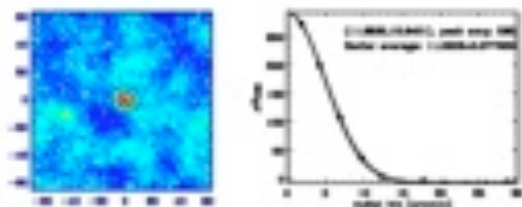


Figure 3.11: (PKS)0518-45

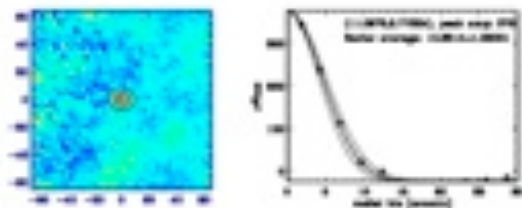
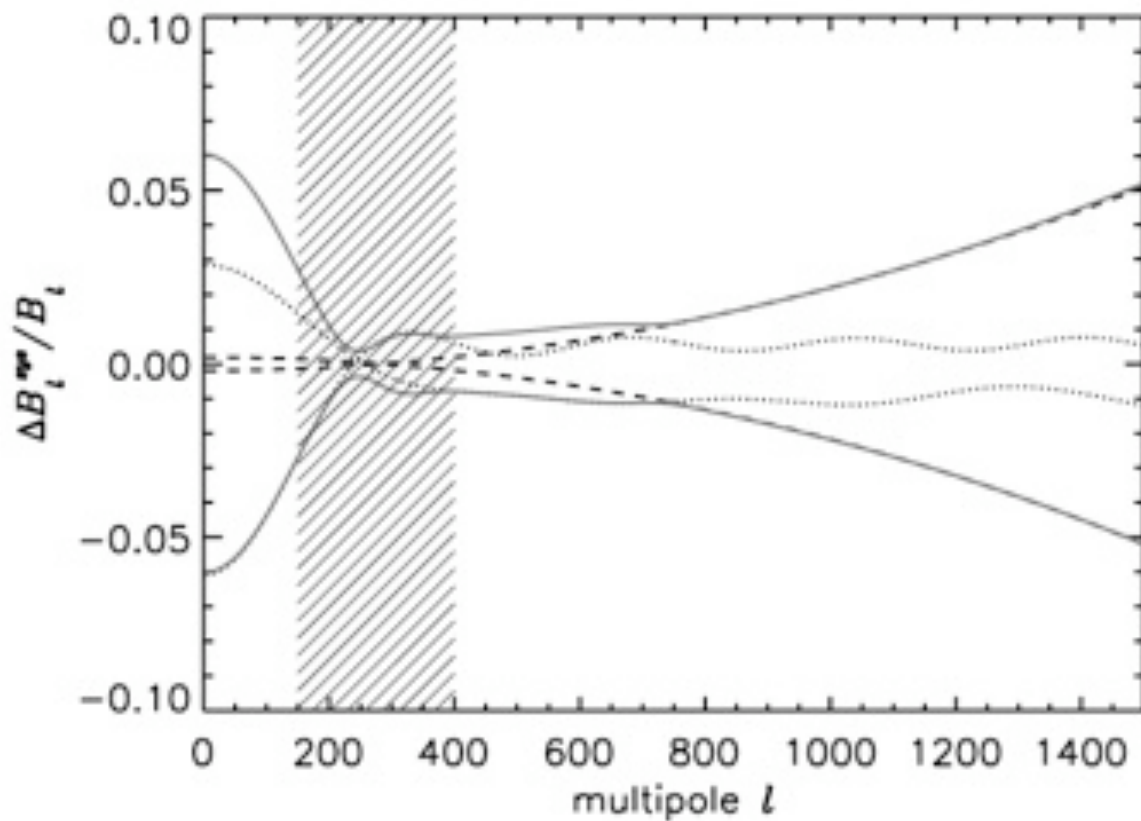
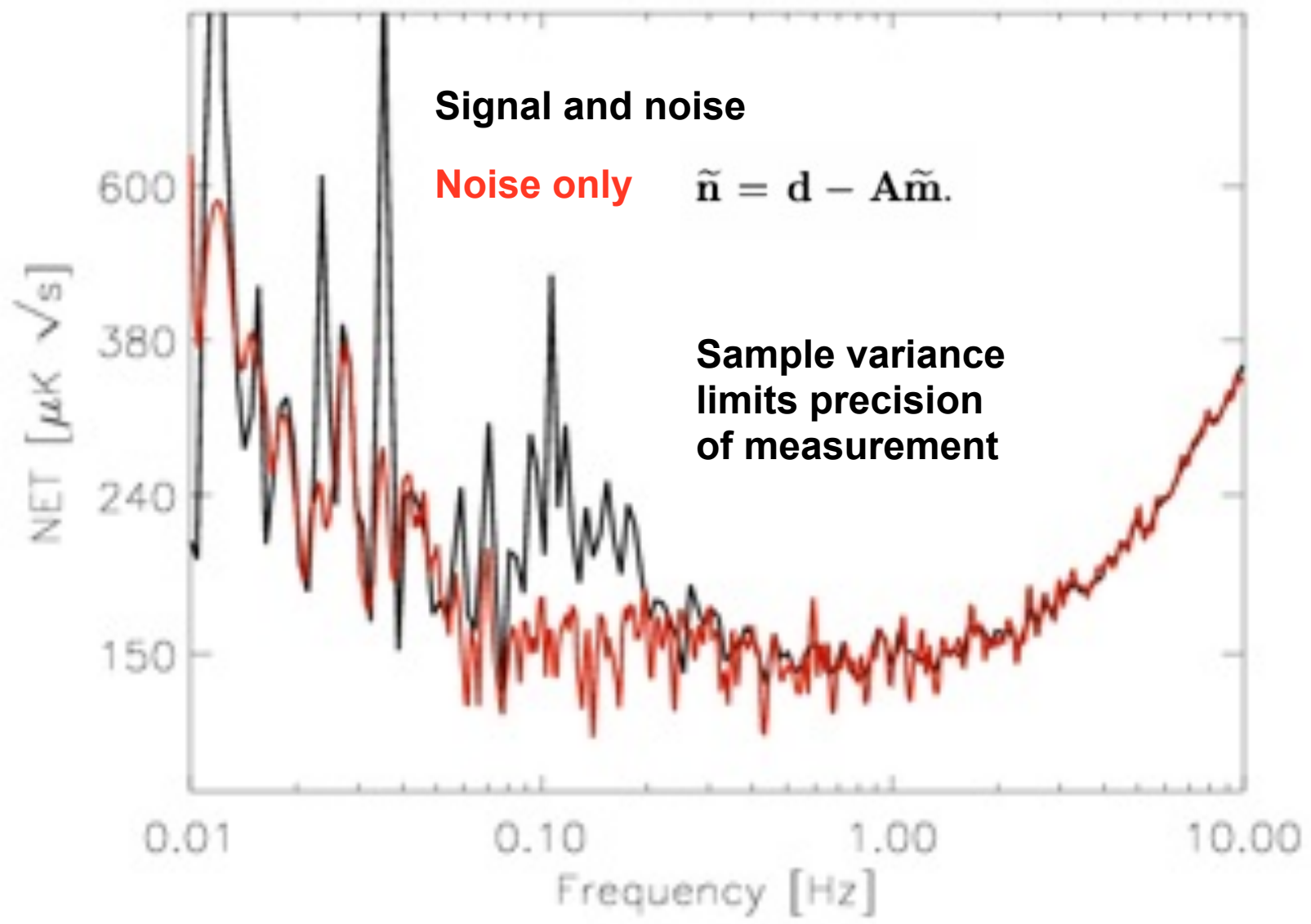


Figure 3.12: (PKS)0454-46

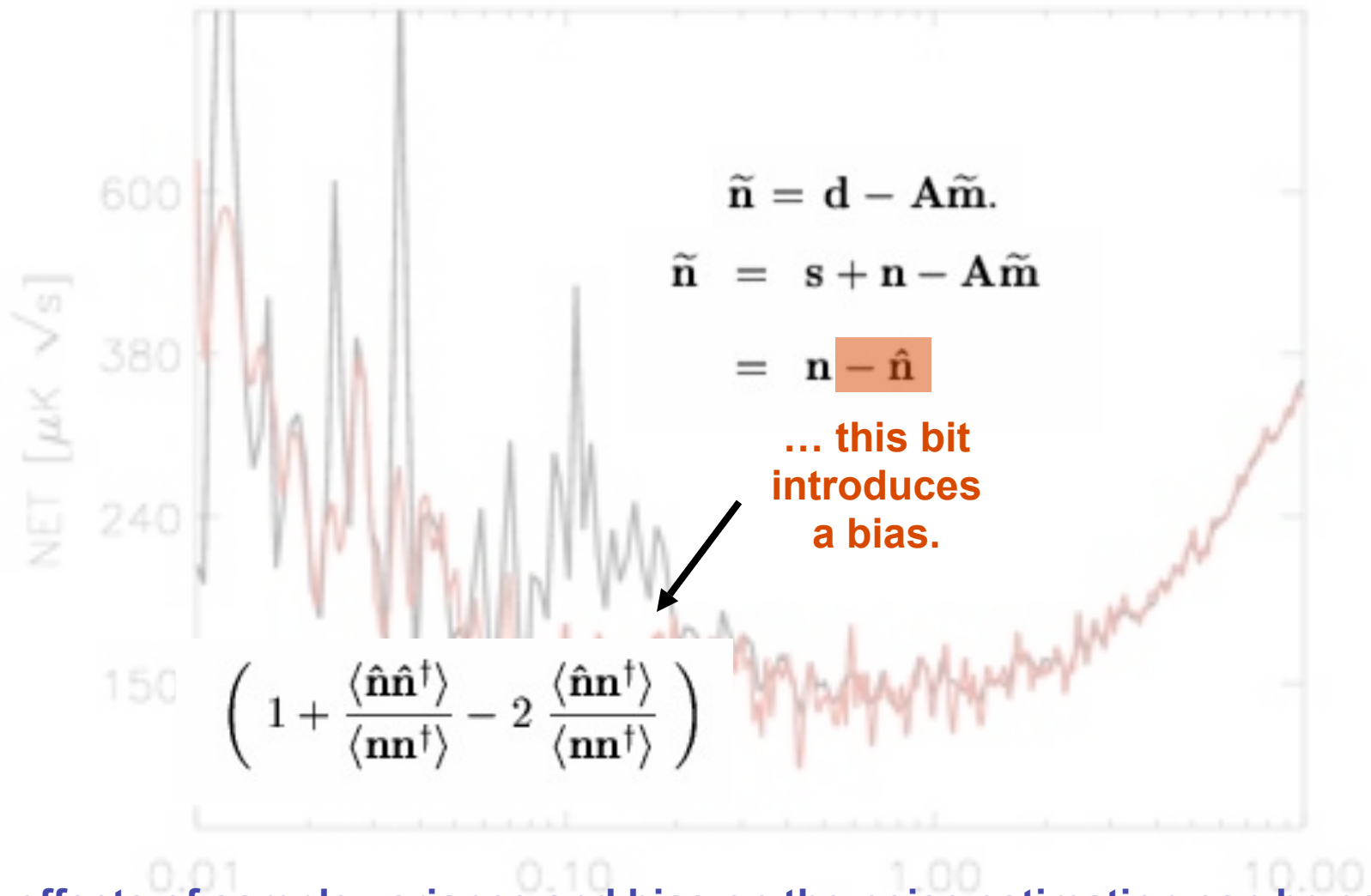
Beam window functions: extrapolating from the angular scale of the calibration



# Signal and Noise Estimation: Precision



# Signal and Noise Estimation: Accuracy

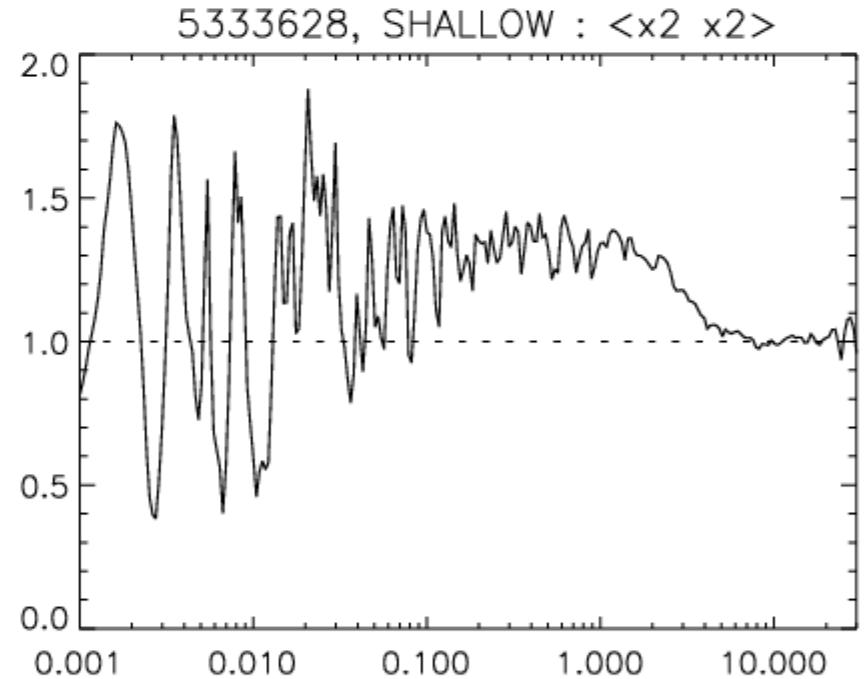
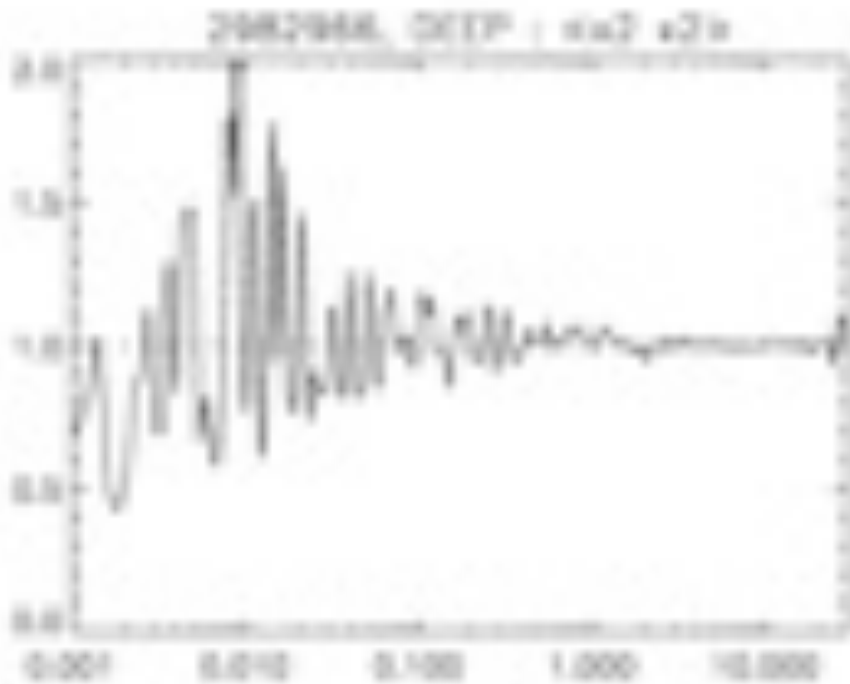


The effects of sample variance and bias on the noise estimation can be easily incorporated into the MC pipeline, or corrected via MC's.



# Signal and Noise Estimation: Accuracy

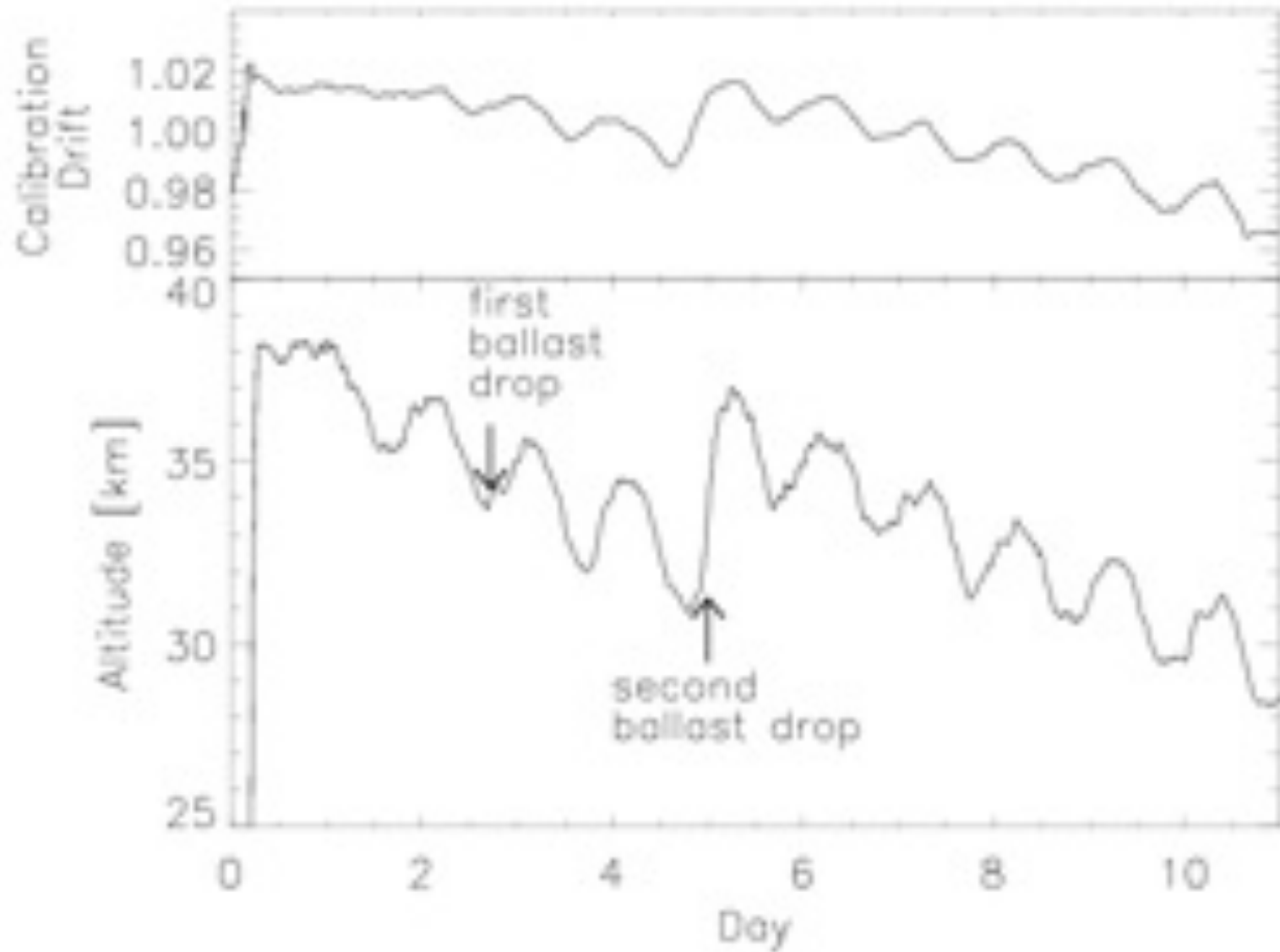
## Ensemble average transfer function of signal & noise MCs



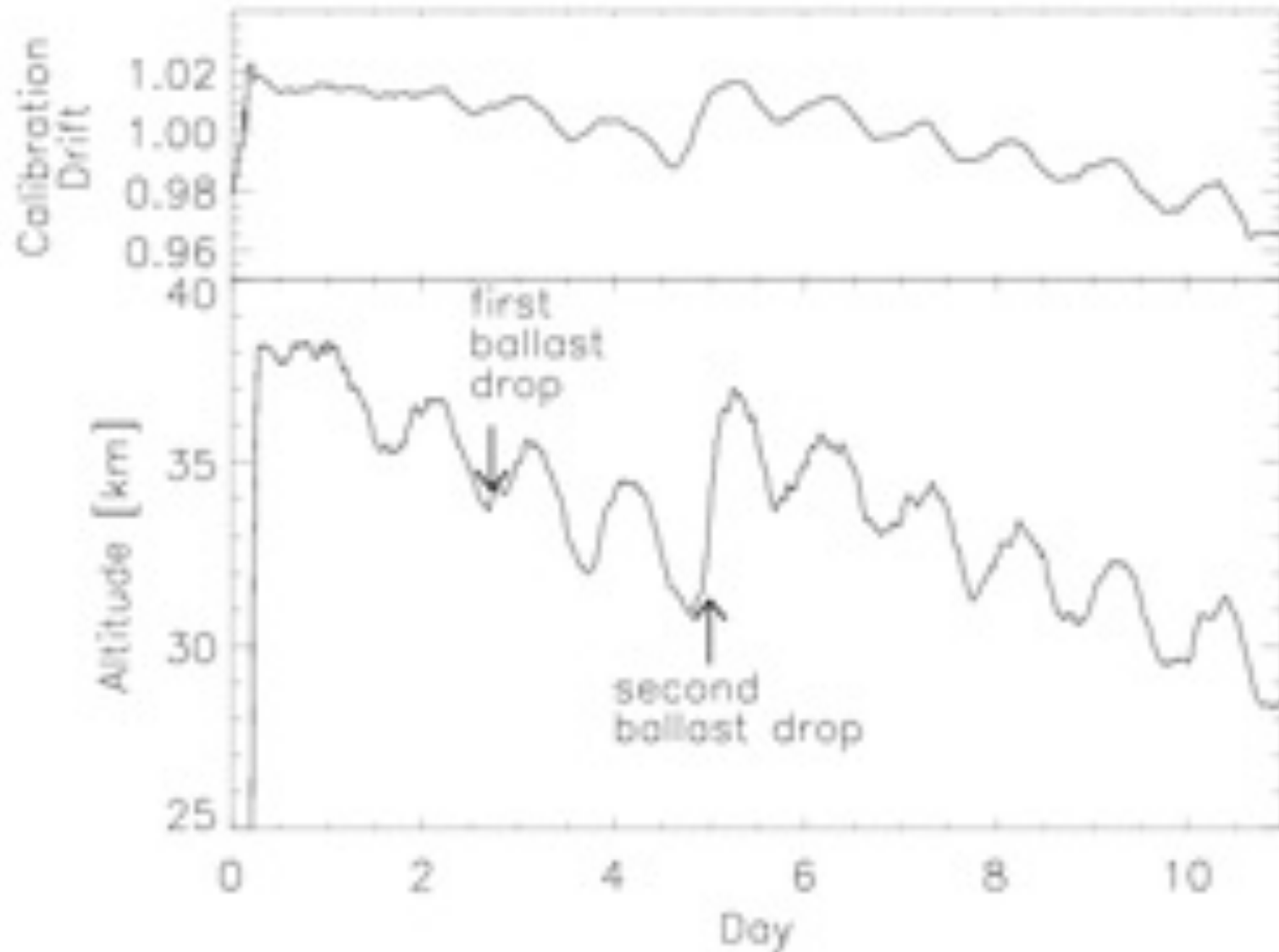
$$\langle \tilde{C}_l \rangle = \sum_{l'} M_{ll'} F_{l'} B_{l'}^2 \langle C_{l'} \rangle + \langle \tilde{N}_l \rangle$$

The effects of sample variance and bias on the noise estimation can be easily incorporated into the MC pipeline, or corrected via MC's.

# Environmental Effects

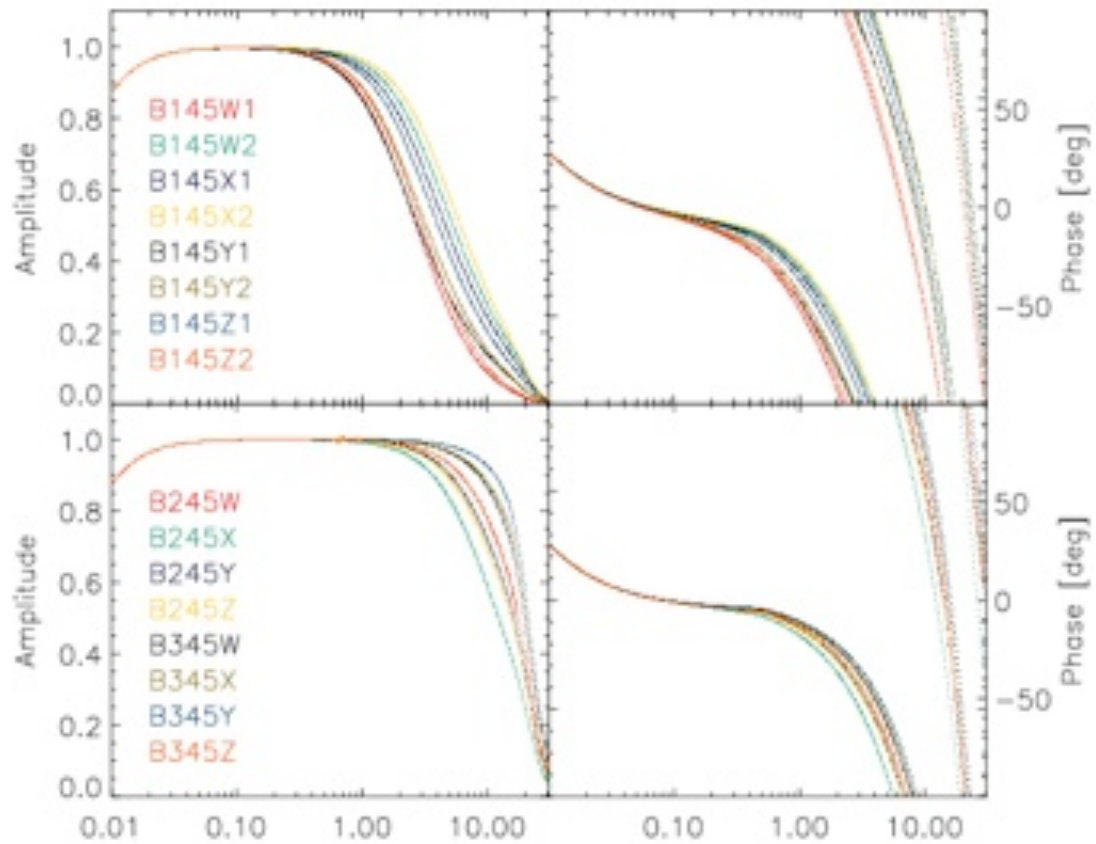


# Environmental Effects

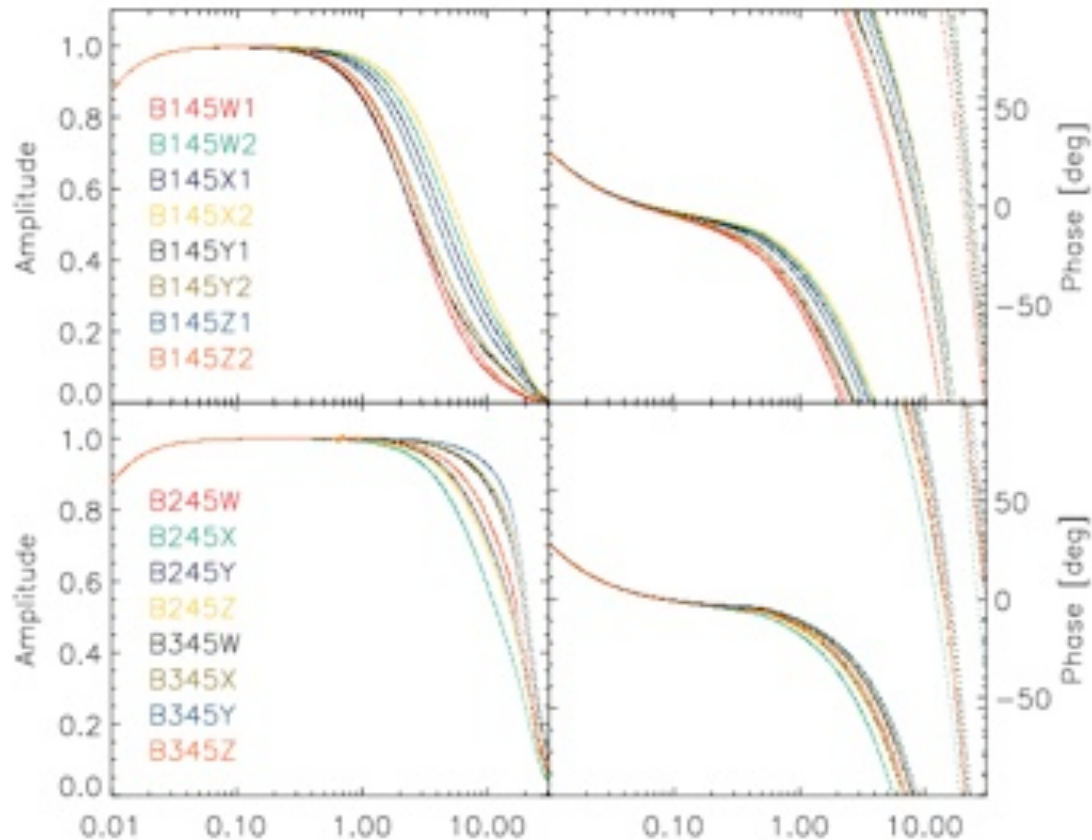


**We like to think we planned it this way...**

# Transfer functions



# Transfer functions



**Errors amount to a really complicated gain mismatch**

# Boomerang 2003: Issues/Lessons/Concerns

- A well **cross-linked map** is critical for high fidelity polarimetry
  - Both scan strategy and polarization modulation (**sky rotation/scan**)
- Knowledge of **absolute polarization angles**
  - Overall focal plane offset (**preflight measurements**)
- Understanding the solid angle of the  $< \sim 30$  dB sidelobes
  - Required for extrapolating calibration to other scales (**beam maps**)
- Unbiased **noise model**
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- Characterization/stability of the **detector transfer functions**
  - Can generate spurious polarization (**not well characterized in flight**)
- Beam shapes not significant: science well below beamscale







# Systematics to consider

Below is a list of potential systematic effects. Please address whatever effects you can from here in your talk; feel free to add more or qualify/expand on these. Quantitative limits (measured, calculated, or estimated) on these effects would be helpful, as would results of simulations with your observing strategy that take them to a power spectrum.

<b>Systematic</b>	<b>Effect</b>
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	$dT_{\text{opt}} \rightarrow B$
Scan modulated cold stage variations	$dT_{\text{CS}} \rightarrow B$
Band shape errors, including modulator effects	foregrounds $\rightarrow B$
Others?	?

# BOOMERANG flights: 1998 and 2003

