

Upcoming CMB Polarization Experiments

Ken Ganga

A Measurement of Excess Antenna Temperature at 4080 Mc/s

A.A. Penzias & R.W. Wilson

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value of about 3.5 K higher than expected. This excess temperature is, within the limits of our observations, isotropic, [unpolarized](#), and free from seasonal variations (July, 1964 - April, 1965). A possible explanation for the observed excess noise temperature is the one given by Dicke, Peebles, Roll, and Wilkinson (1965) in a companion letter in this issue.

ApJ, 142: 419-421

Further Limits/Detections on Polarization

- Caderni et al., 1978
- Nanos, 1979
- Lubin and Smoot, 1979/81
- Lubin et al., 1983
- See also Sironi et al., 1997
- Partridge et al., 1997
- Subrahmanyam et al. 2000
- Saskatoon
- Archeops
- COLD
- POLAR
- PIQUE
- COMPASS
- CBI
- DASI
- CBI?

-
- WMAP and Company (now – 2005)
 - Near-Term Experiments (2005 – 2008)
 - Mid-Term Experiments (2007-?)
 - Future Experiments (2017+?)

WMAP Information

Wilkinson Microwave Anisotropy Probe

Technology : HEMT

Platform : Satellite

Frequencies : 23, 33, 41, 61, 94 GHz

Telescope : 1 m back-to-back Gregor.

NET/Detector : 0.8, 0.8, 1.0, 1.2, 1.6 mK $\sqrt{\text{Hz}}$

Location : 2nd Sun-Earth Lagrange

of Detectors : 4, 4, 8, 1

Start Date : 27th Feb 2001

Beam Size : 35, 18, 31, 21, 13

Duration : 4 years (?)

Missions :

Sky Fraction : 1.0 (Full Sky)

Efficiency : 100%

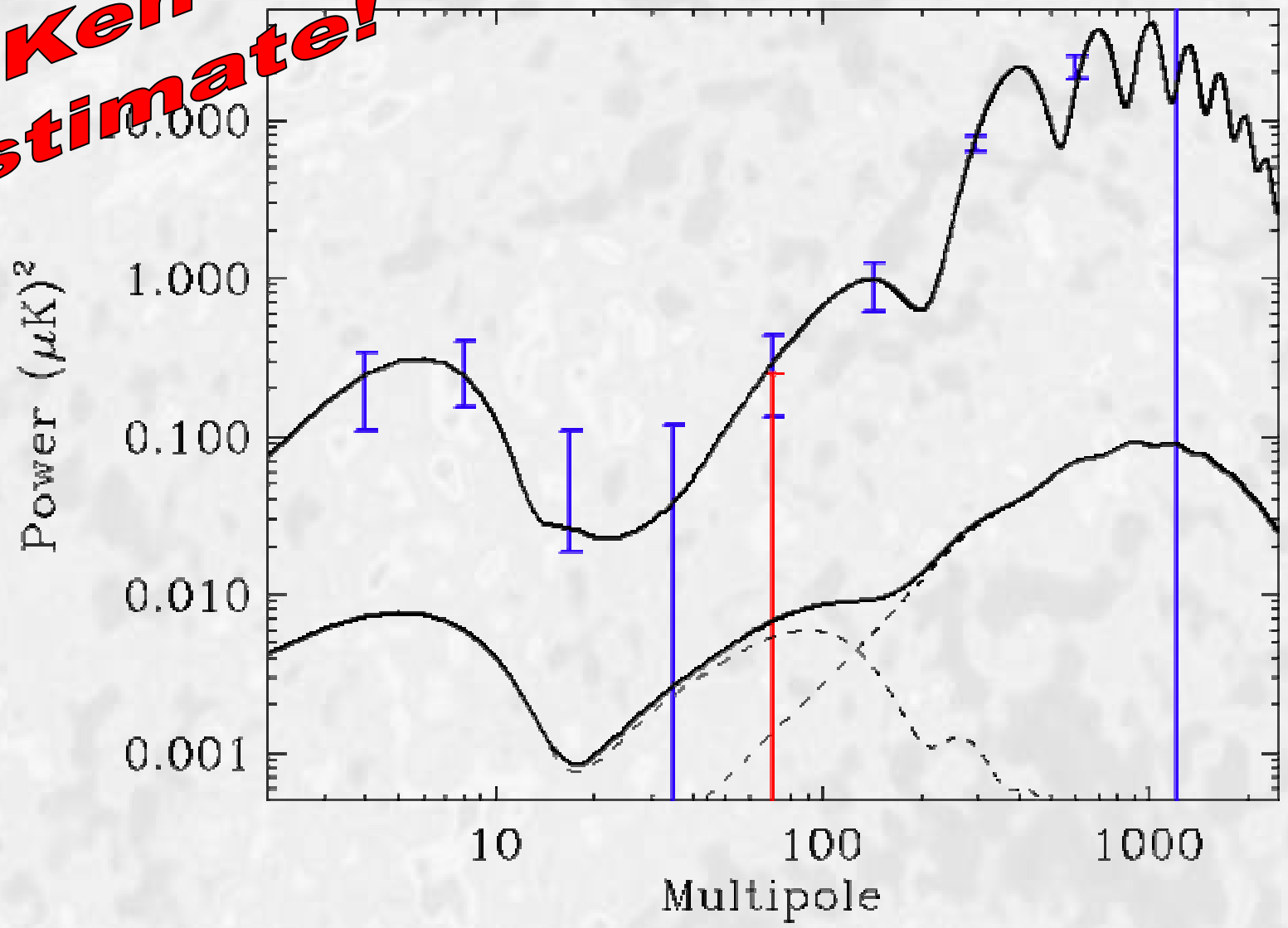
PI(s) : Gary Hinshaw (GSFC)

Reference : Wilkinson Microwave Anisotropy Probe (WMAP): Explanatory Suppl.

Web Page : lambda.gsfc.nasa.gov

WMAP94

**Ken's
Estimate!**



SPOrt Information

Sky Polarization Observatory

Technology : Correlation Polarimeters

Platform : Space

Frequencies : 22, 32, 90 GHz

Telescope : Corrugated feed horns

NET/Det. : -, -, $530 \mu\text{K}_{\text{CMB}}\text{S}^{1/2}$

Location : International Space Stat'n

of Det. : 2, 2, 4

Start Date : 2007?

Beam Size ('): 420 (7°)

Duration : 1.5 years

Multipoles : 2—30

Sky Fraction : 0.8

Efficiency : 100%

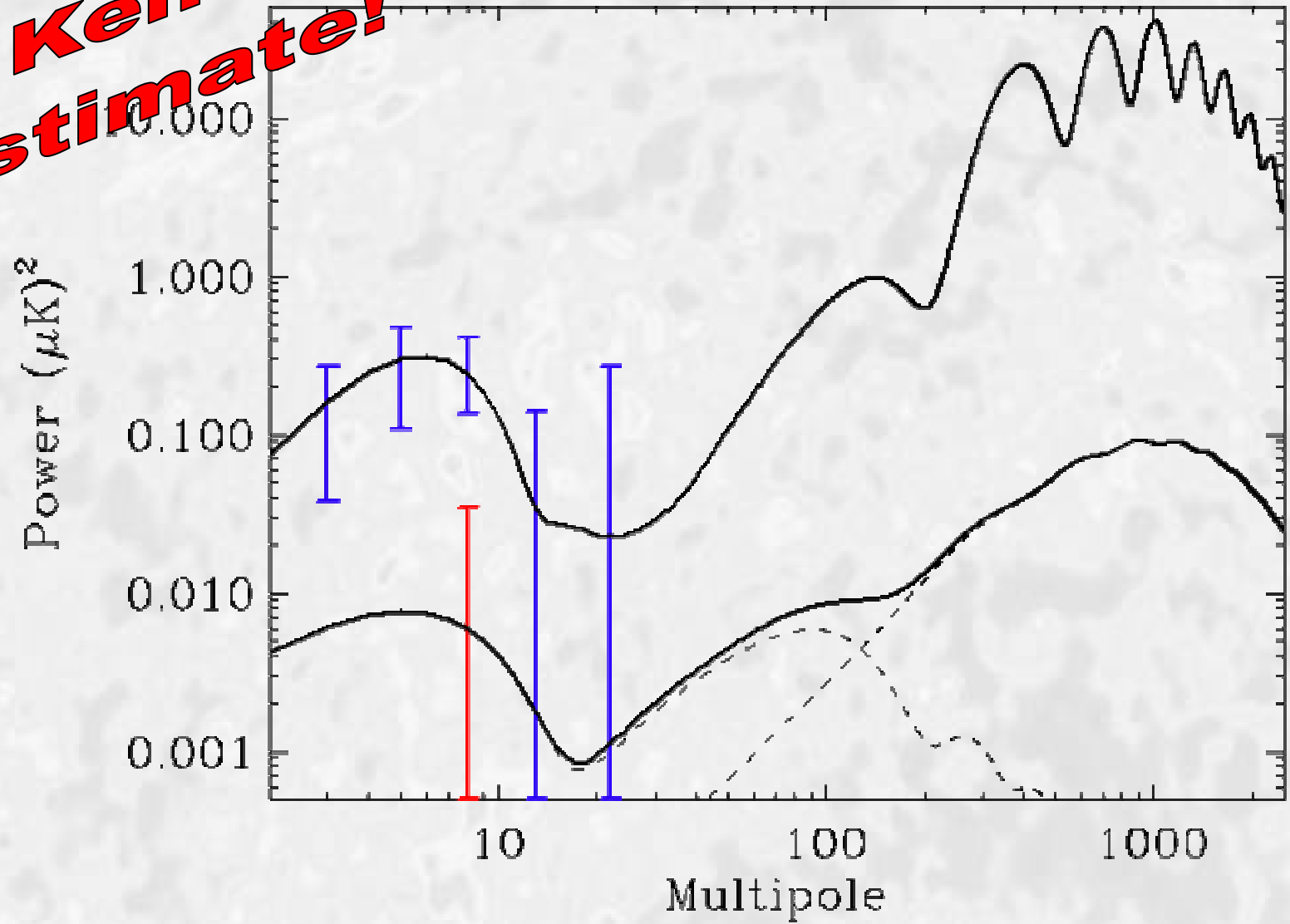
PI(s) : Stefano Cortiglioni

Reference : New Astronomy, **9**, 297-327 (2004)

Web Page : <http://sp0rt.bo.iasf.cnr.it:8080/index.php>

SPORT

**Ken's
Estimate!**



CAPMAP

Cosmic Anisotropy Polarization MAPper

Technology : Hetero. Corr. Pol.

Platform : Ground-based

Frequencies : 40, 90 GHz

Telescope : 7 m, Off-Ax., Cas.

NET/Array : $200 \mu\text{K}_{\text{CMB}}\text{s}^{1/2}$

Location : Crawford Hill, NJ

of Det. : 4, 12

Start Date : 50% deployed

Beam Size (') : 6, 4

Duration : 2 years

Multipoles : 500-1500

Sky Fraction : $2 \cdot 10^{-5}$ (1° cap)

Efficiency :

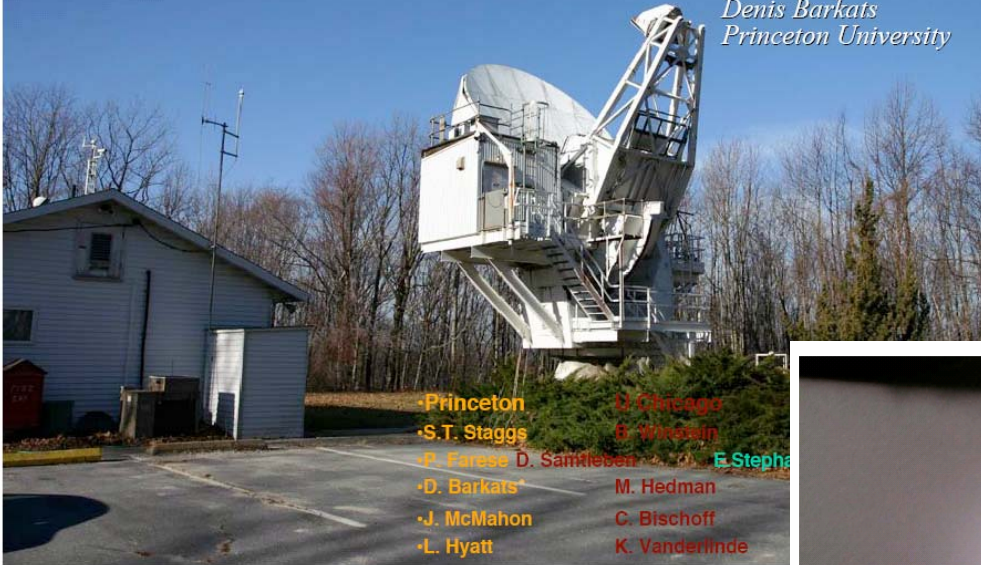
PI(s) : Suzanne Staggs (Princeton)

Reference : Barkats, 2003, New Ast. Rev. **47**, 1077–1081.

Web Page : <http://cosmology.princeton.edu/capmap/webpage/homepg.html>

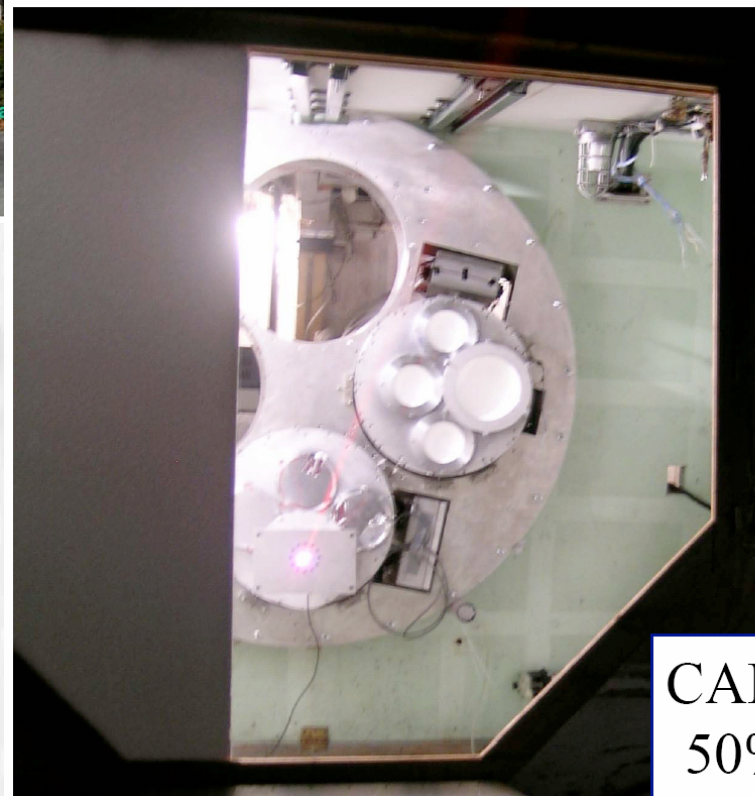
CAPMAP : A 16 Element Array for Measuring the E-mode Polarization of the CMB

Denis Barkats
Princeton University



-Princeton
-S.T. Staggs
-P. Farese
-D. Barkats
-J. McMahon
-L. Hyatt
-U. Chicago
-G. Wineman
-D. Sanzleban
-E. Stepha
-M. Hedman
-C. Bischoff
-K. Vanderlinde

Stolen from
Denis Barkats
Jan. 2004

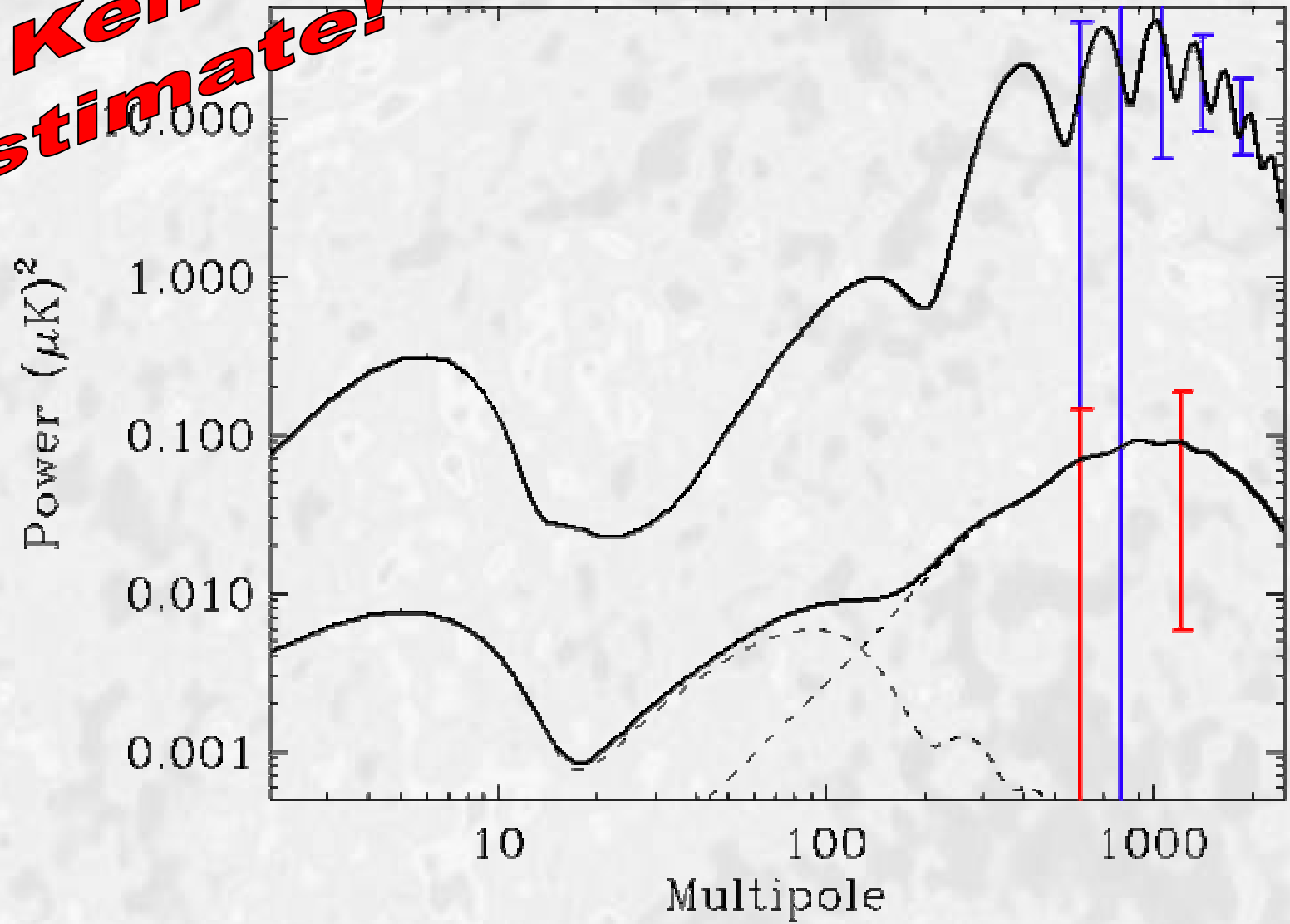


A Large
Focal Plane

CAPMAP 2004:
50% Deployed

CAP90

**Ken's
Estimate!**



BOOMERaNG Information

Balloon Observations of Millimetric Extragalactic Radiation aNd Geomagnetics

Technology : Bolometers

Platform : Balloon

Frequencies : 145, 245, 345 GHz

Telescope : 1.3 m off-axis Cassegrain

NET/Det. : 150, 350, 800 $\mu\text{K}_{\text{CMB}}\text{S}^{1/2}$

Location : Antarctica

of Det. : 8, 4, 4

Start Date : January, 2003

Beam Size (') : 9.5, 6.5, 7

Duration : 12 days

Multipoles :

Sky Fraction : 0.003 (123 deg.²)

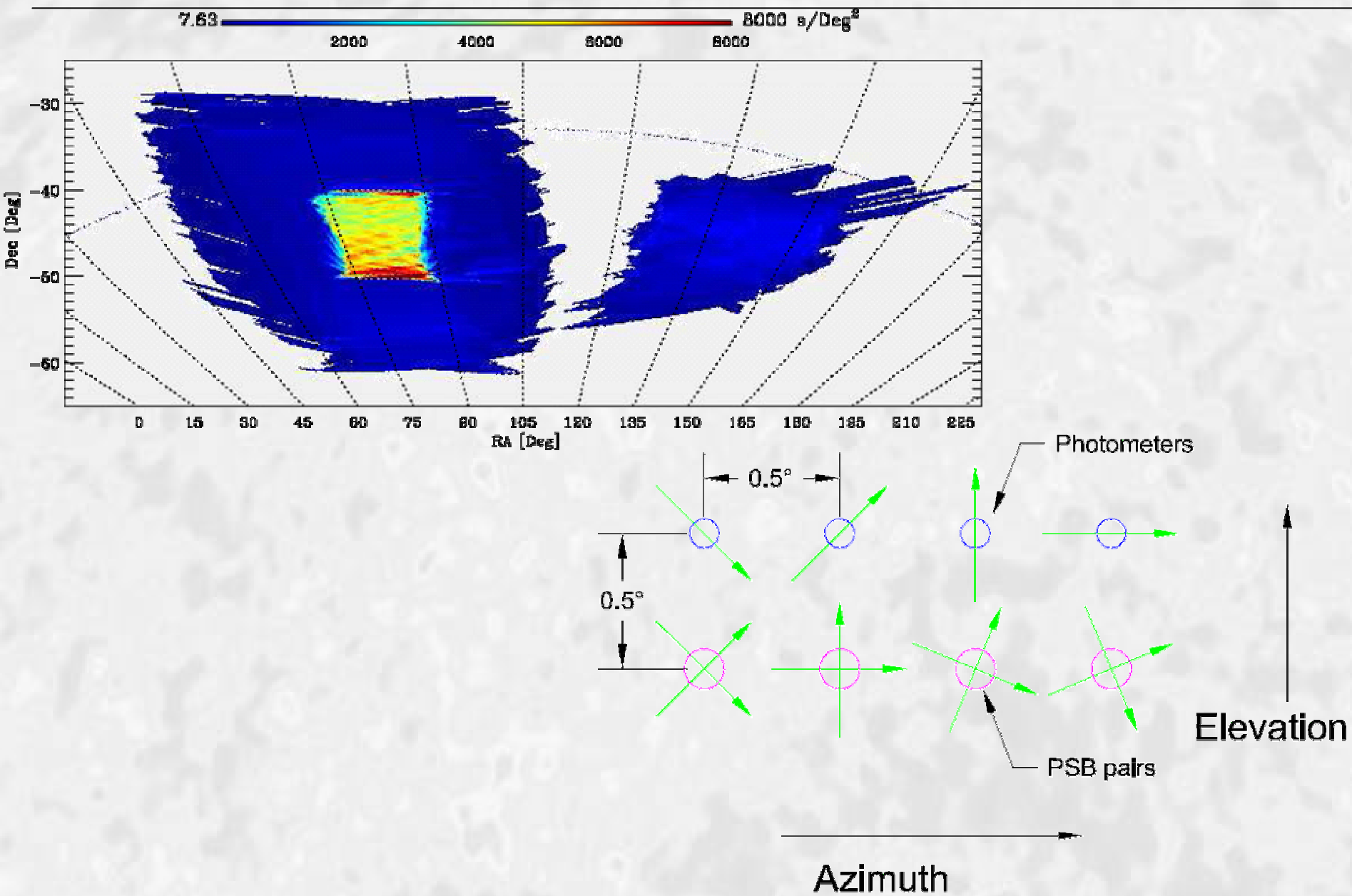
Efficiency :

PI(s) : John Ruhl (CWRU); Paolo DeBernardis (Rome)

Reference : http://www.astro.caltech.edu/~lgg/boomerang_instr.htm

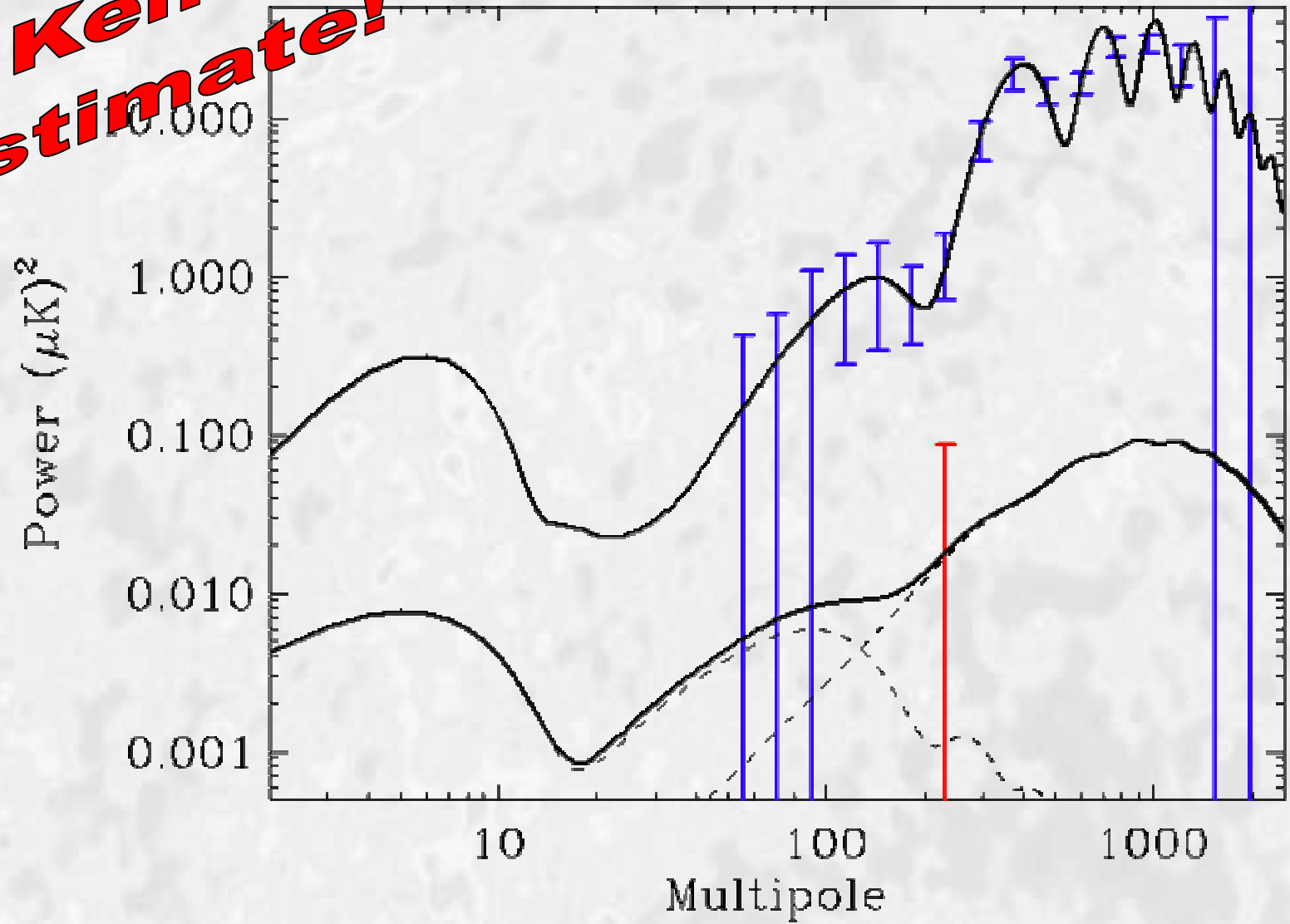
Web Page : http://www.astro.caltech.edu/~lgg/boomerang_front.htm

B2K



B2K150

**Ken's
Estimate!**



- We should have multiple detections of the E-E power spectrum
- We should have upper limits on the B-B spectrum
- We should have a much better understanding of how difficult it will be to make out the features in the polarization spectra

Near Term

AMiBA Information

Array for Microwave Background Anisotropy

Technology : HEMT

Platform : Ground-based

Frequencies : 90 GHz

Telescope : Interferometer

NET/ARRAY: $100 \mu\text{K}_{\text{CMB}}(\text{hr})^{1/2}$

Location : Mauna LOA, HI; USA

of Det. : 19

Start Date :

Beam Size (') : 2

Duration : 100 nights

Multipoles : 700 – 2000

Sky Fraction : 0.0002 ($2.9^\circ \times 2.9^\circ$)

Efficiency :

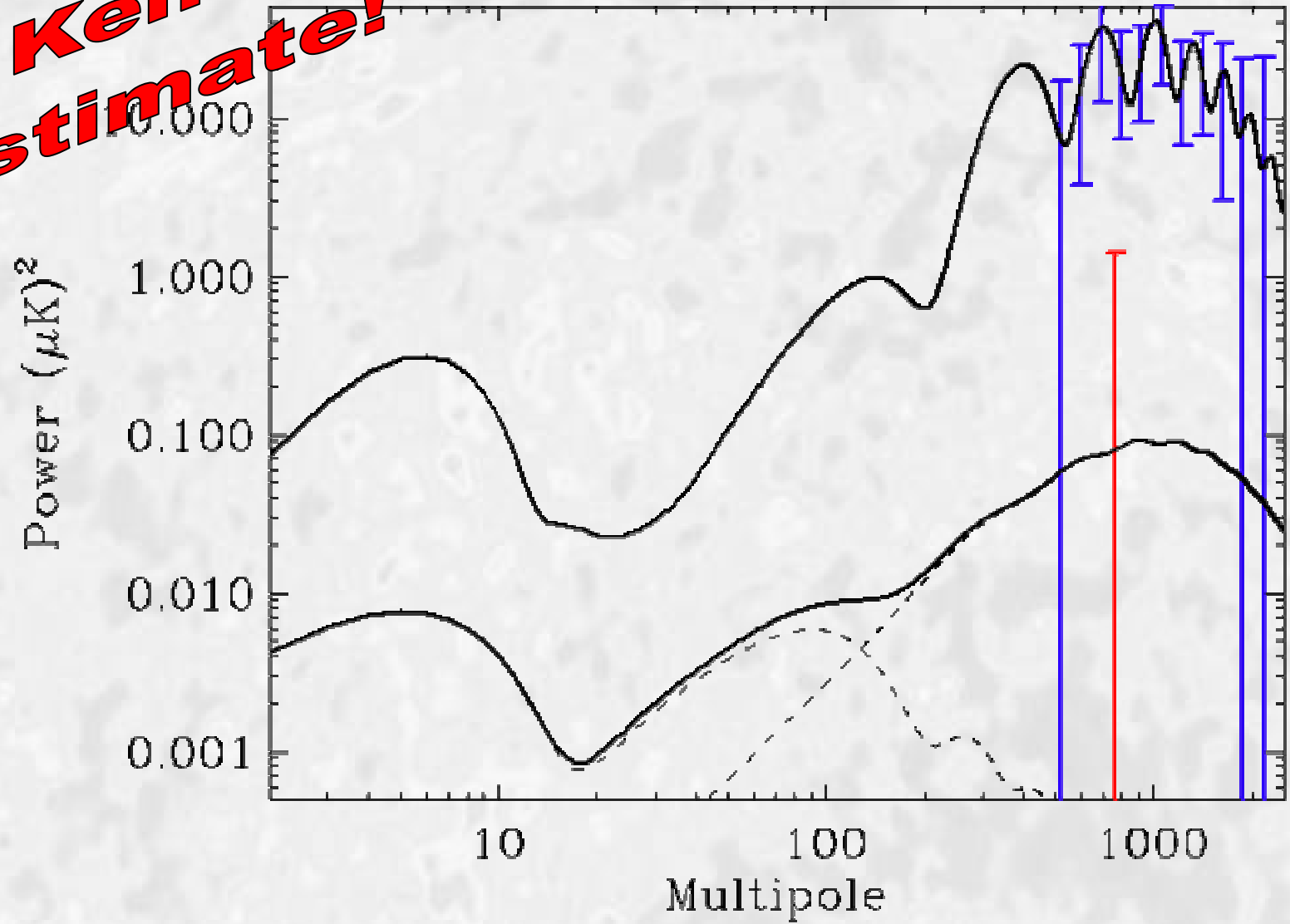
PI(s) : Dr. Sun Kwok

Reference :

Web Page : <http://amiba.asiaa.sinica.edu.tw/>

AMIBA

Ken's Estimate!



QUaD

QUEST (Q/U Extragalactic Submillimeter Telescope) and DASI

Technology : PS Bolometers

Platform : Ground-Based

Frequencies : 100, 150 GHz

Telescope : On-Axis

NET/Det. : 270, 300 μK_{CMB}

Location : South Pole

of Det. : 24, 38

Start Date : February, 2005

Beam Size (') : 4.2, 6.0

Duration : 2 Austral Winters

Multipoles :

Sky Fraction : 0.0073 (300 deg.²)

Efficiency :

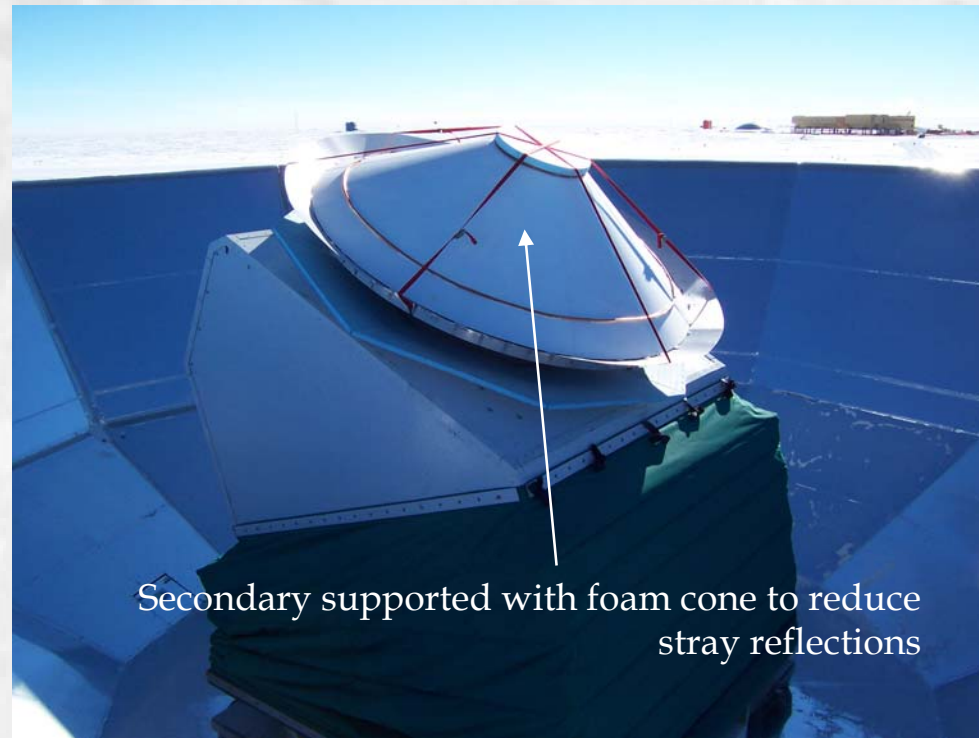
PI(s) : Church (Stanford); Gear (Cardiff)

Reference : Church *et al.* (2003), *New Ast. Rev.*, **47**, Issue 11-12, 1083

Web Page : <http://www.astro.cf.ac.uk/groups/instrumentation/projects/quest/>

Quick QUaD Facts

- Designed specifically for polarization measurements
 - 100 and 150 GHz
 - Angular resolution of 4-6'
 - 300 square degrees of sky
 - Bolometric array receiver mounted on a 2.6 m telescope
- Comprises the QUEST experiment mounted on the DASI platform at the South Pole (QUEST at DASI – QUaD)
- Extremely stable environment with very low water vapor emission – ideally suited for CMB astronomy

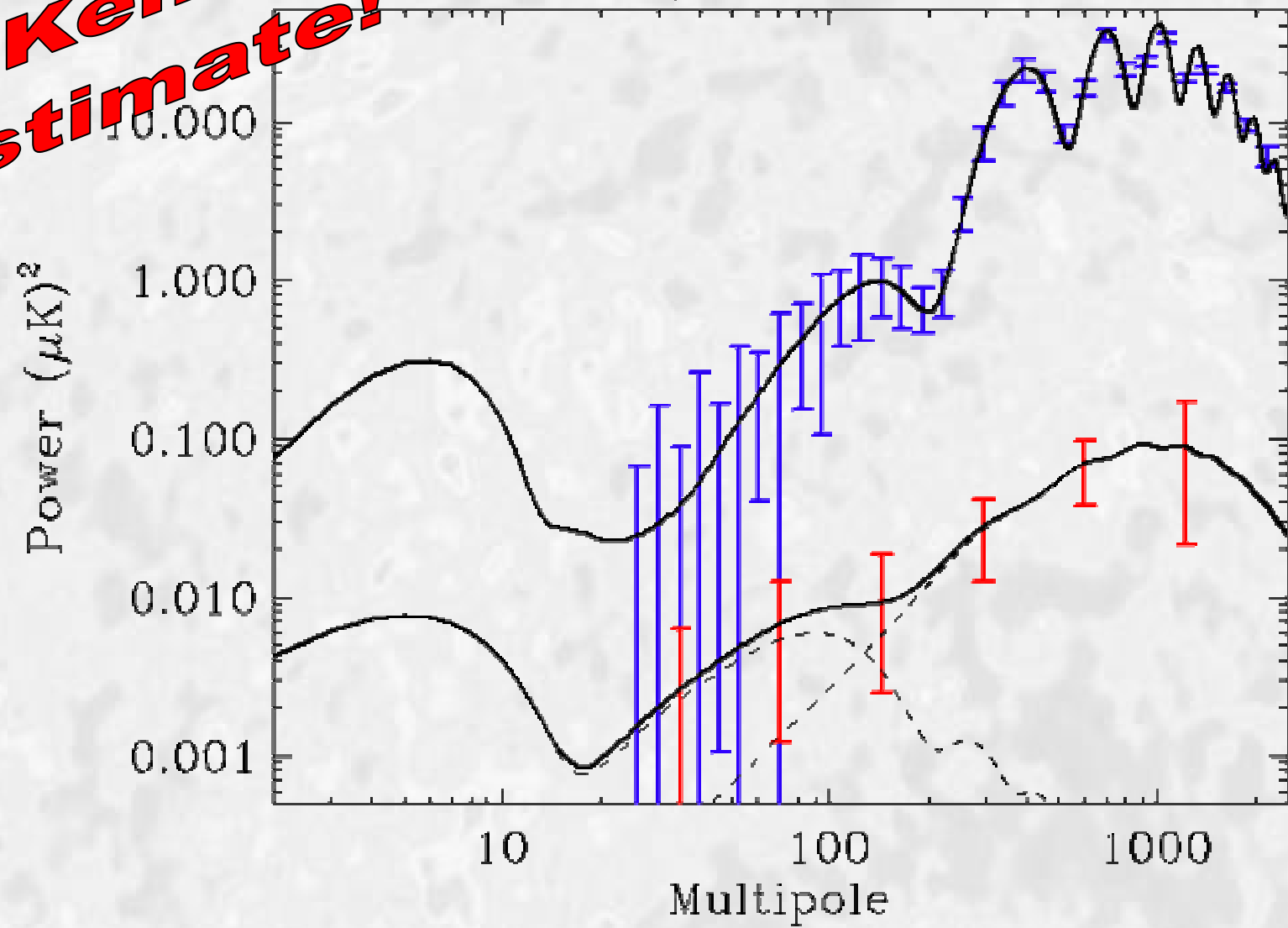


Freq (GHz)	Beam (')	# Feeds	% Bandwidth	NET/bolo. ($\mu\text{K}\cdot\text{s}^{1/2}$)
100	6.3	12	25	270
150	4.2	19	25	300

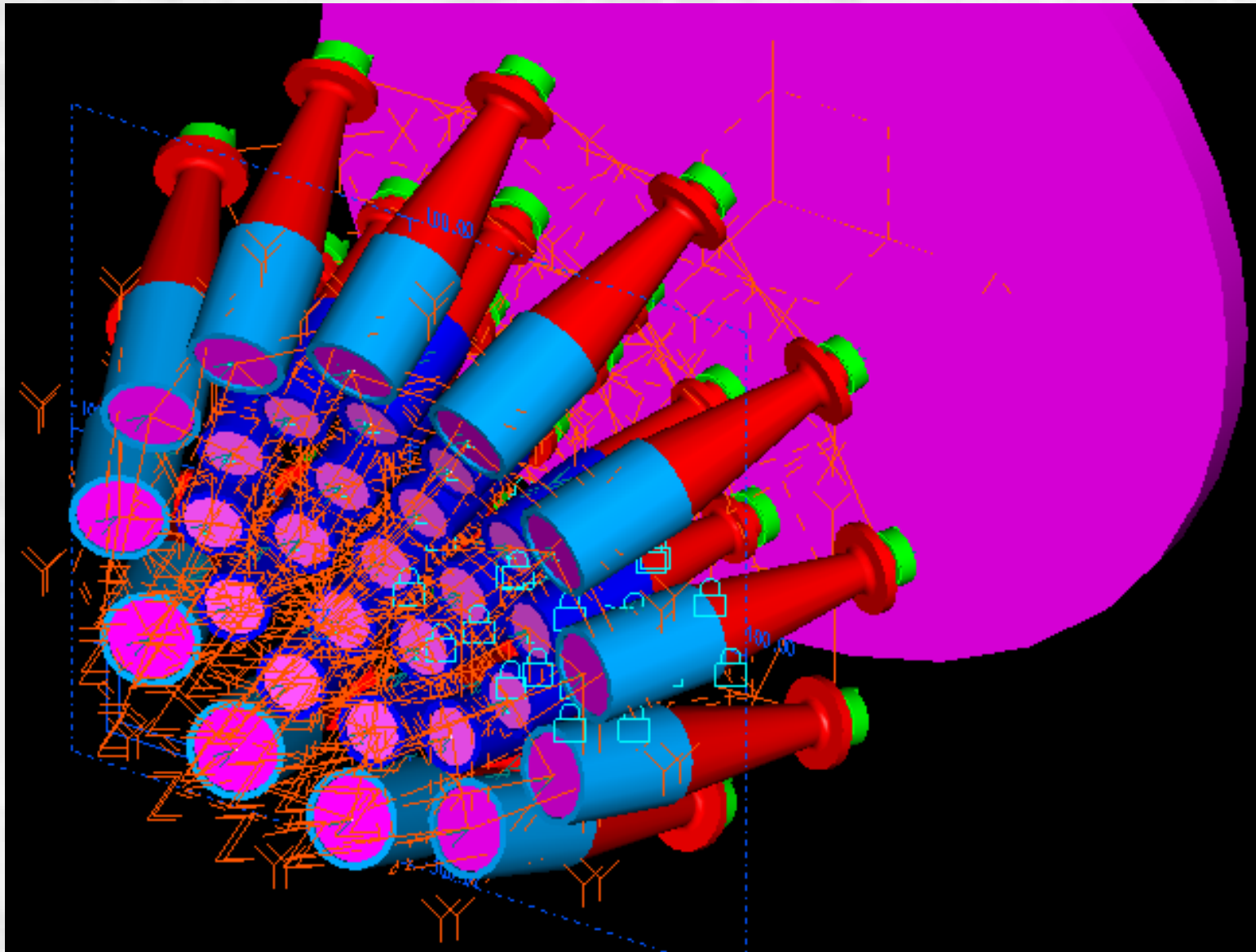
Predicted QUaD Spectra

Ken's Estimate!

QUaD150



QUaD Focal Plane



BICEP Information

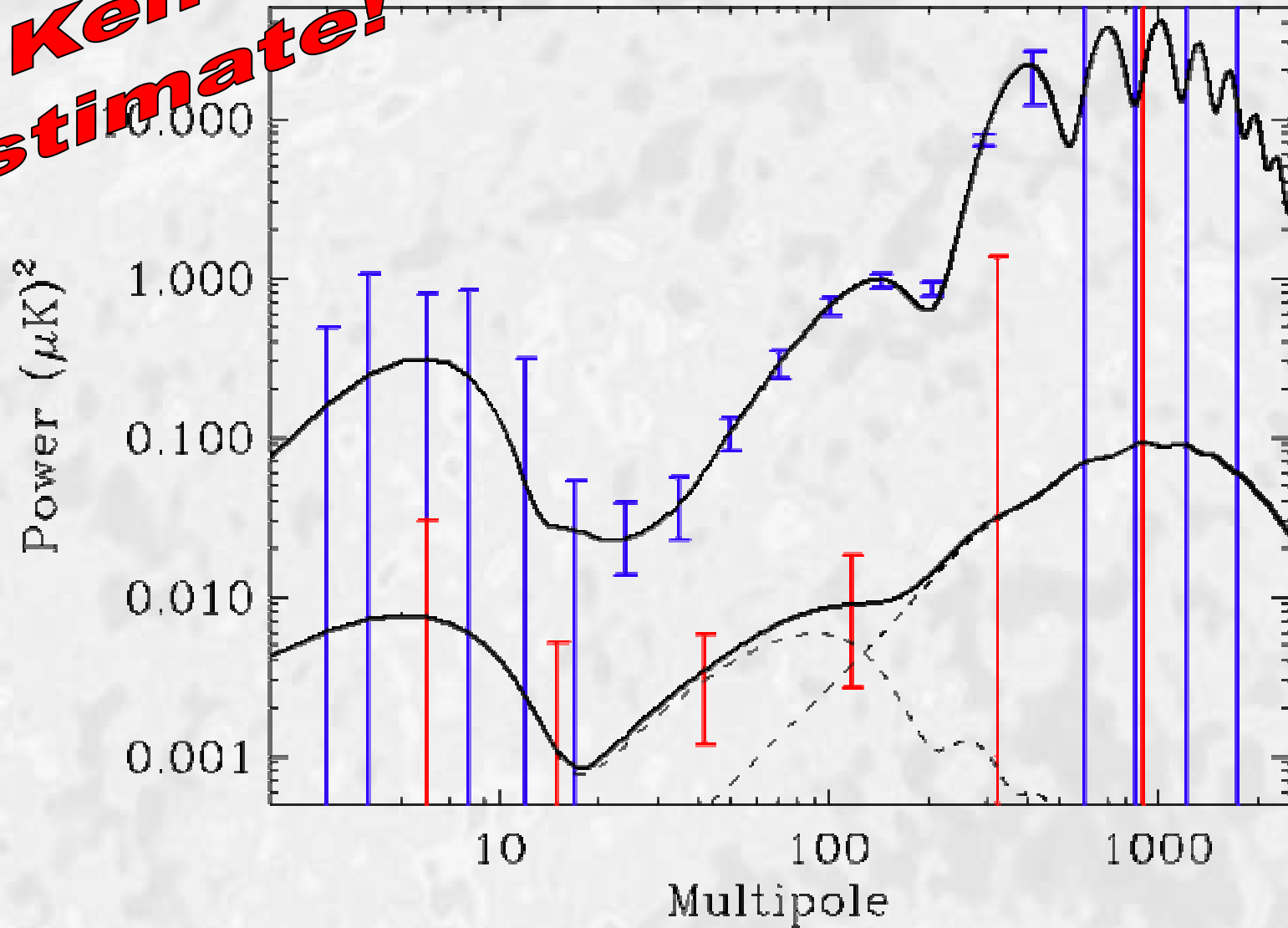
Technology : Pol. Sens. Bolometers	Platform : Ground Based
Frequencies : 100, 150 GHz	Telescope :
NET/Det. : 280, 280 $\mu\text{K}_{\text{CMB}}\text{S}^{1/2}$	Location : South Pole
# of Det. : 48, 48	Start Date : February, 2005
Beam Size (') : 60, 40	Duration : 2 austral winters
Multipoles :	Sky Fraction : 0.08
	Efficiency :
PI(s) : Andrew Lange (Caltech)	
Reference :	
Web Page :	

- South Pole site allows for a continuous observation of a contiguous region on the sky – ideal for measuring B-modes
- The BICEP mount will have the capability to tilt from vertical as well as continuous rotation about the dewar boresight at ~ 1 RPM
- Drift scanning will be combined with continuous boresight rotation for a well-connected and modulated map
- Drift-scanning and boresight rotation are combined with frequent calibrations, faraday modulation, and PSB pair differencing to achieve five levels of differencing



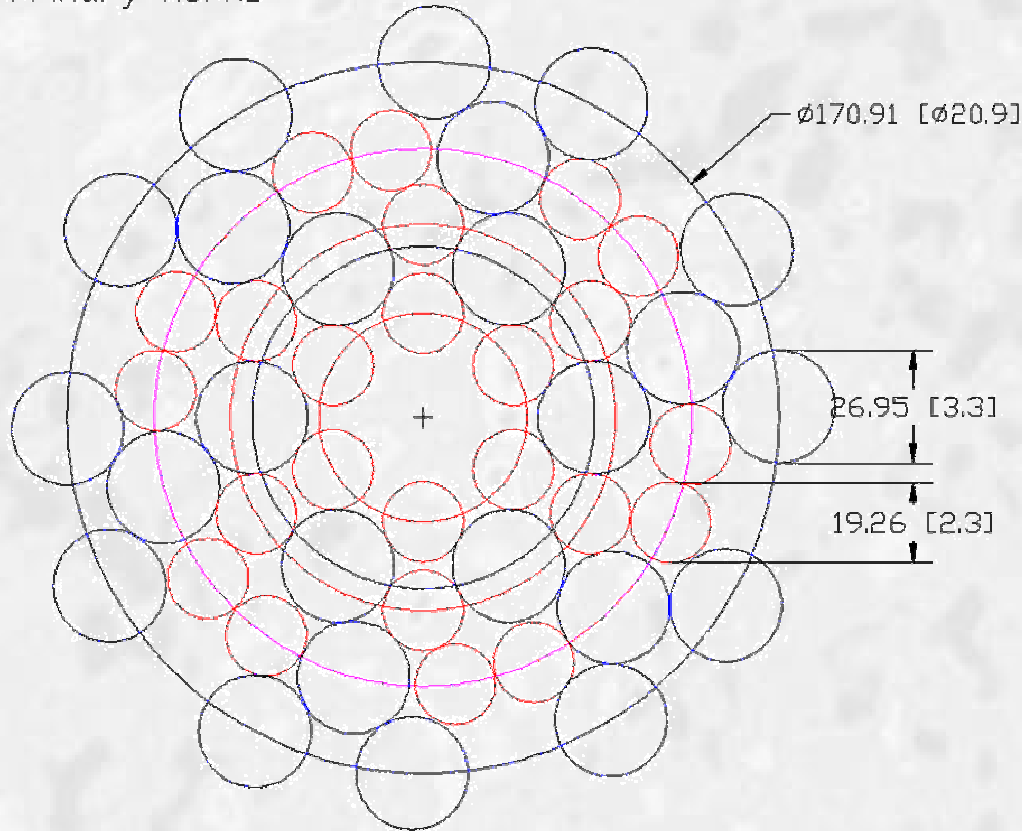
BICEP 150

Ken's Estimate!



BICEP Focal Plane

Primary Horns



- 24 horns / 48 detectors at each frequency
- Pixels arranged in circular rings to take advantage of boresight rotation

~2008

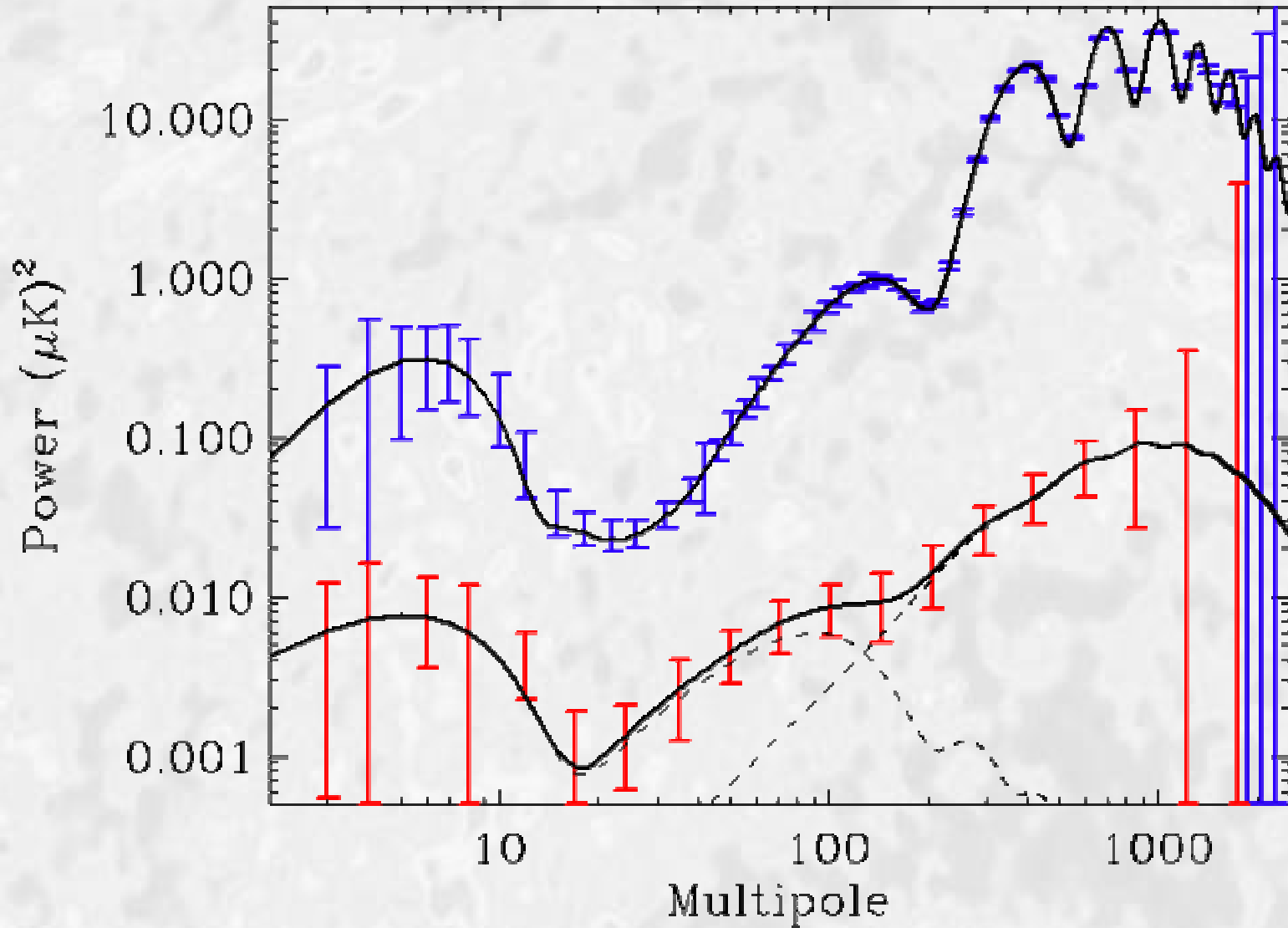
- We will have mapped features in the E-E spectrum
- We should have a detection of B-B lensing spectrum, IGWs if nature is forthcoming...
- A number of initial version of the experiments discussed later will also be coming out with results similar to those discussed previously, if funded...
- Planck should be flying...

Mid Term

Planck Information

Technology : HEMTs and Bolometers	Platform : Satellite
Freq.s (GHz): 30, 44, 70, 100, 143, 220, 353	Telescope :
NET/det. : 170, 200, 270, 51, 56, 81, 253	Location : Sun-Earth 2 nd Lagrange Pt.
# of Det. : 4, 6, 12, 8, 12/8, 12/8	Start Date : 2007
Beam Size : 33, 24, 14, 7.1, 5, 5	Duration : 14 months
Multipole	Sky Fraction 0.
	Efficiency : 0.9
PI(s) : Jean-Loup Delabrouette (IAS) / Nazzeno Mandolesi (Bologna)	
Reference	
Web page : http://sci.esa.int/science-e/www/area/index.cfm?fareaid=17	

PLANCK90



PolarBear Statistics

POLARization of the Background millimEter wAve Radiation

Technology : Antenna-coupled Bolos

Platform : Ground-based

Frequencies : 90, 150, 220 GHz

Telescope : 3m off-axis Dragone

NET/Det. : 310, 345, 640 $\mu\text{K}_{\text{CMB}}\text{s}^{1/2}$

Location : White Mountain, CA

of Det. : 400, 600, 200

Start Date : (Mid-2006) 2007-8

Beam Size (') : 6.7, 4, 2.7

Duration : (1-year) 1.5 years

Multipoles :

Sky Fraction : 0.0054 (225 deg.²)

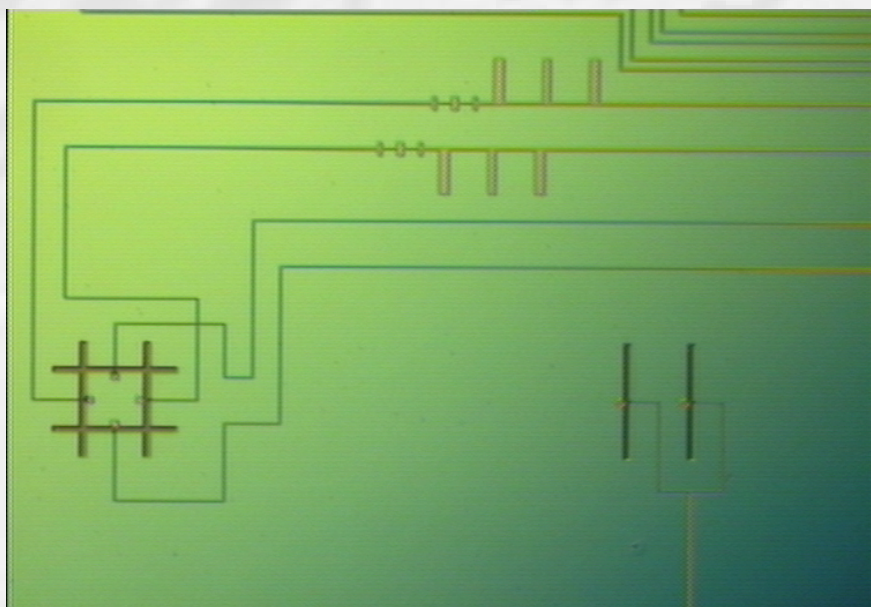
Efficiency : 30% (60% of night time)

PI(s) : Adrian Lee (Berkeley/LBL)

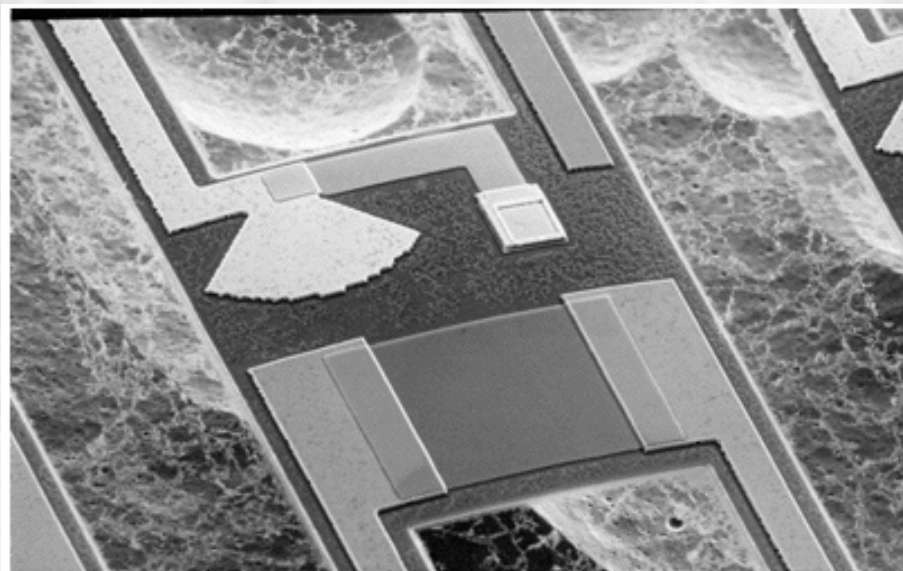
Reference : Adrian Lee

Web Page :

New Detector Technology: Radiometer on a Chip



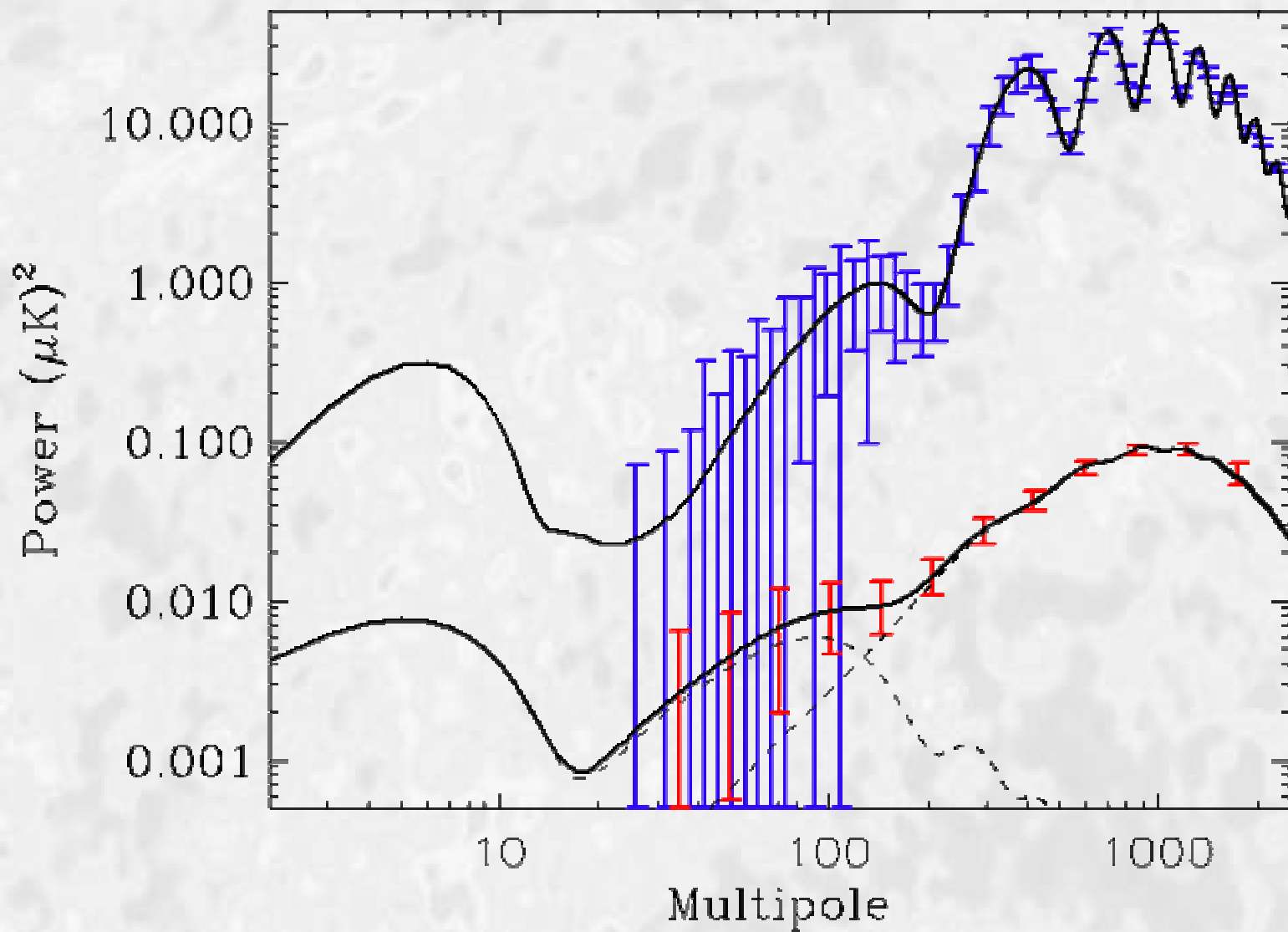
1 mm



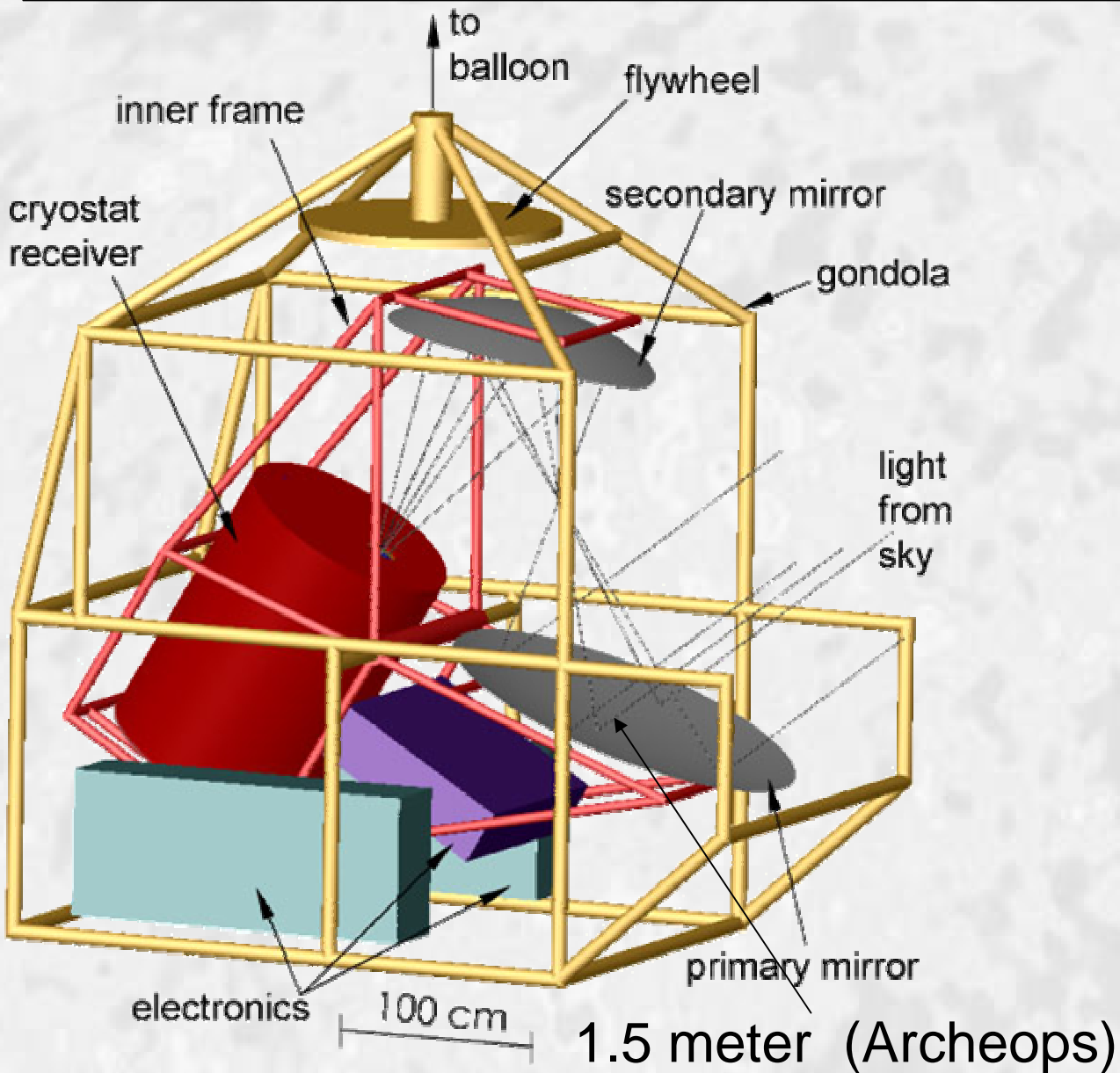
50 micron

- Bolometer Detector at 300 mK
 - Required Sensitivity Achieved
- Large Arrays possible using photolithography (scalable technology)
- Berkeley Plays Pioneer Role -- Initial Investigation with NSF grant

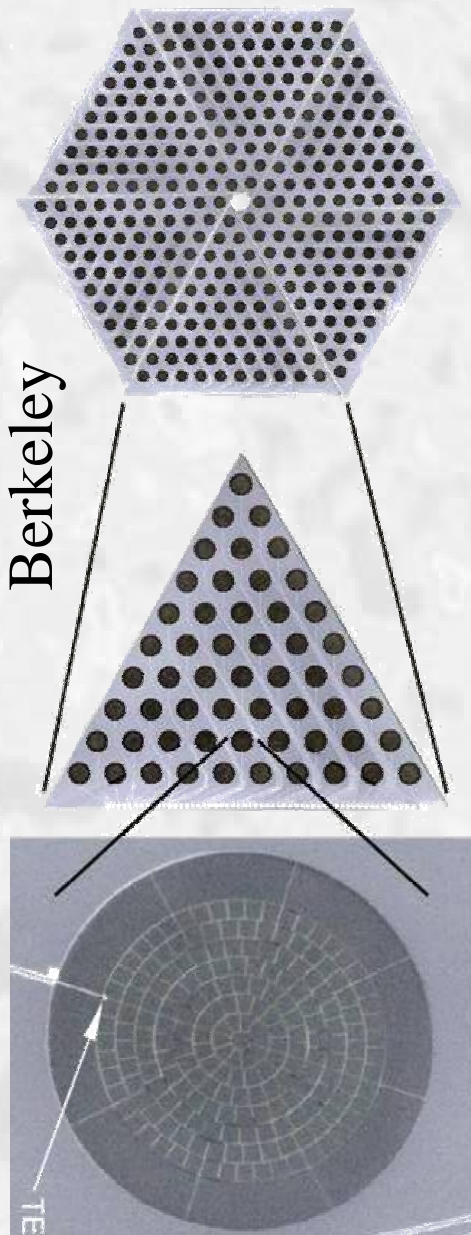
POLARBEAR150



EBEX



TES Bolometers from Berkeley



EBEX Information

E/B mode EXperiment

Technology : TES Bolometers

Platform : Long-Duration Balloon

Frequencies : 150, 250, 350, 450 GHz

Telescope : 1.5 m

Sensitivity : $0.5 \mu\text{K}_{\text{CMB}}/8'$ pixel@150

Location : Antarctica

of Det.* : 660, 330, 180, 150

Start Date : 2007-8

Beam Size (') : 8, -, -, 3

Duration : 14 days

Multipoles : 25-2000

Sky Fraction : 0.008 (350 square deg.)

Efficiency :

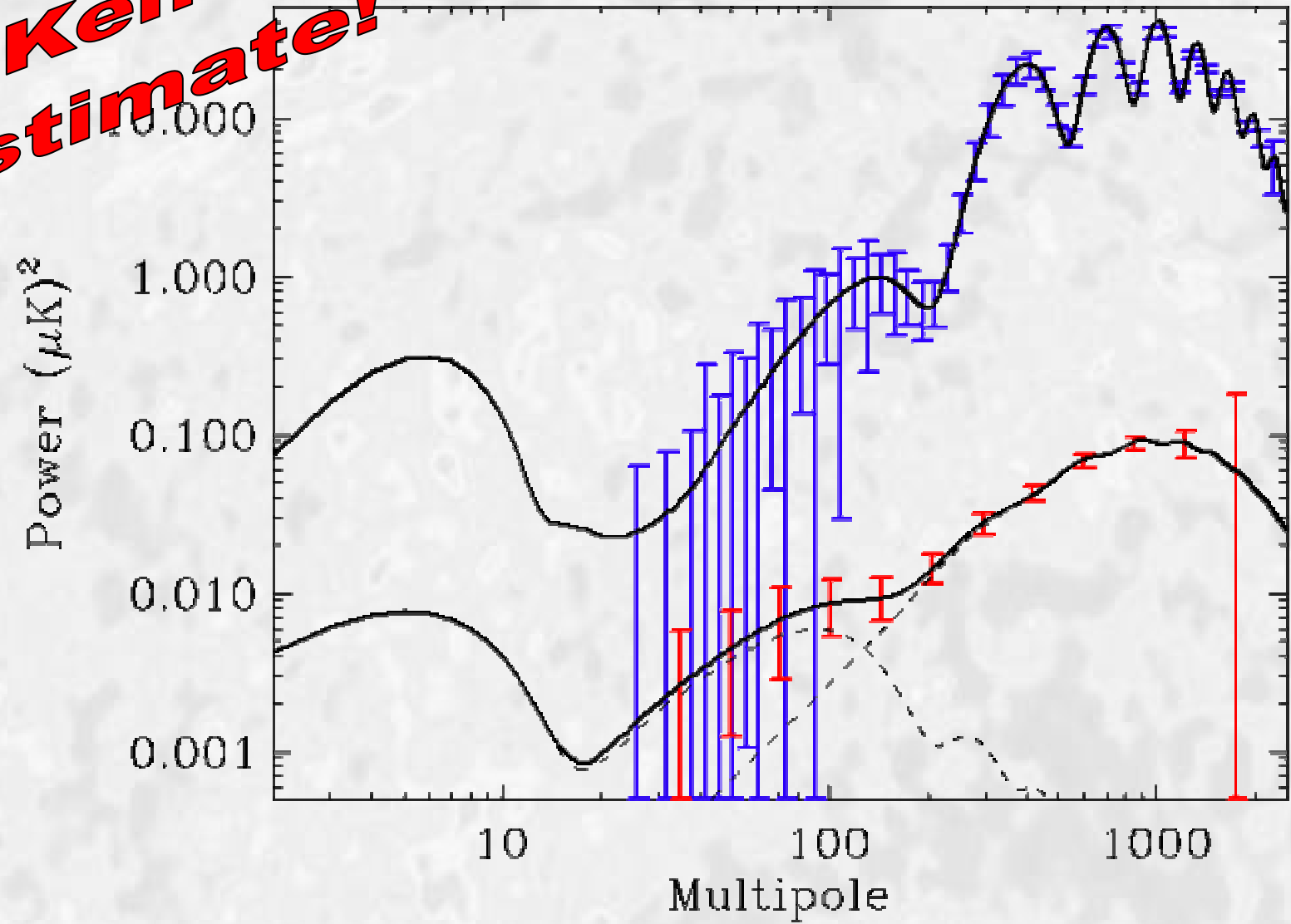
PI(s) : Shaul Hanany (Minn.)

Reference :

Web Page : <http://groups.physics.umn.edu/cosmology/maxipol/>

EBEX

**Ken's
Estimate!**

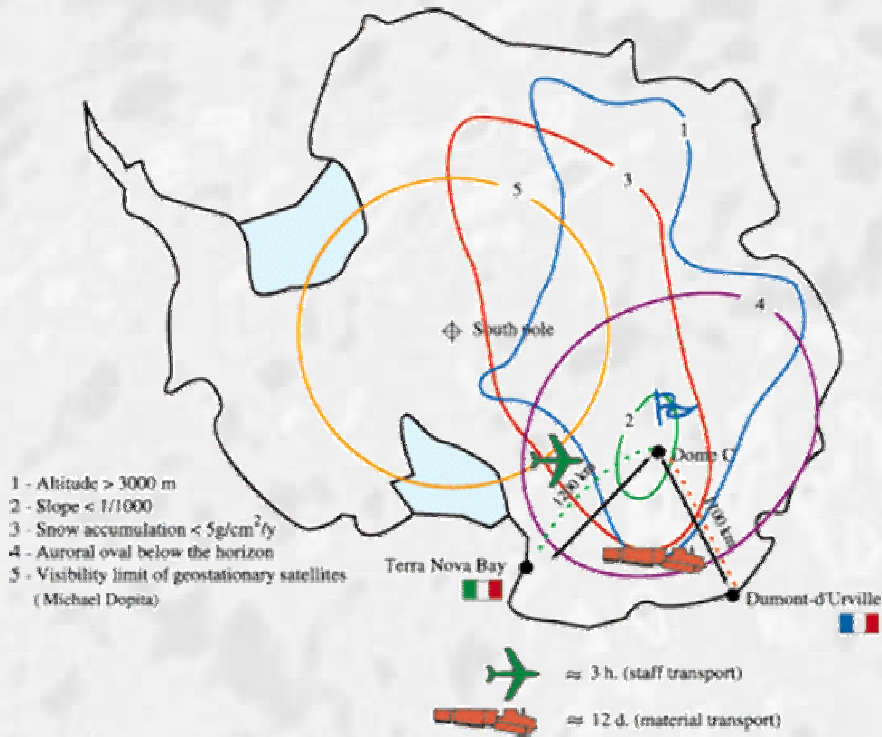


ClOver

C_l ObserVER

Technology	: TES Bolometers	Platform	: Ground-Based
Frequencies	: 90, 150, 220 GHz	Telescope	: 3 assemblies with 4 te.
NET/Det.	: 170, 215, 455 μK_{CMB}	Location	: Dome C (<u>Antarctica</u>)
# of Det.	: 256, 256, 256	Start Date	: 2008
Beam Size (')	: 15', 15', 15'	Duration	: 4500 hours
Multipoles	: 20-1000	Sky Fraction	: 15 deg. dia. ring
		Efficiency	:
PI(s)	: Walter Gear		
Reference	:		
Web Page	:		

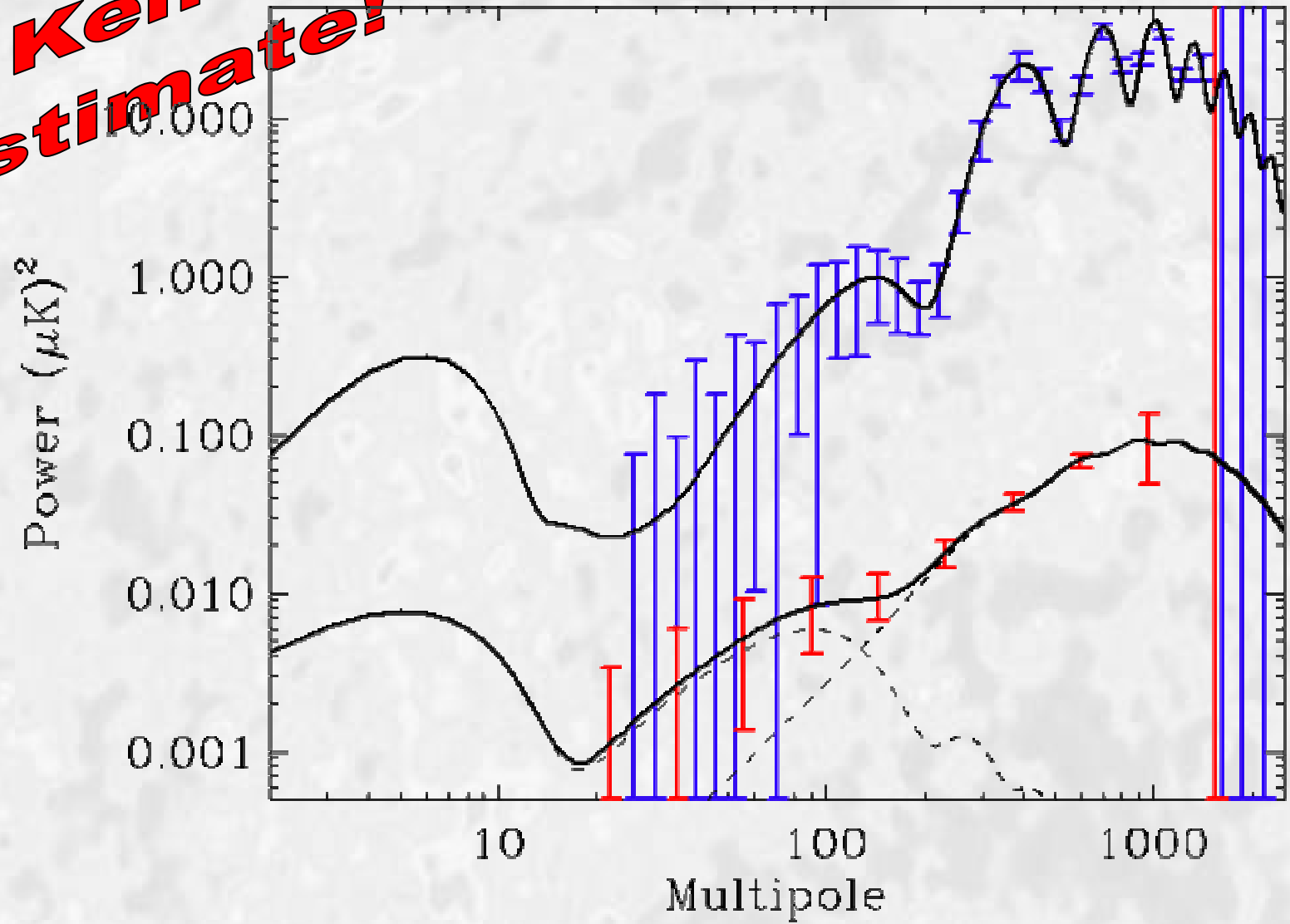
Dome Concordia



Also the site for BRAIN, a bolometric interferometer, using some of the same technology as CLOVER. A 4-element array is planned for late 2005, with a 256 element planned on these “mid-term” time scales.

CLOVER90

Ken's Estimate!



QUIET Information

Q/U Imaging Experiment

Technology :

Platform : Ground based

Frequencies : 90 GHz

Telescope

NET/Det. : $315 \mu\text{K}_{\text{CMB}}\text{S}^{1/2}$

Location : Chile

of Det. : 1000

Start Date : 2006 (approx 100 feeds)

Beam size (')

Duration : 3 months

Multiplexing :

Sky fraction : 0.1 (4000 deg.²)

Efficiency :

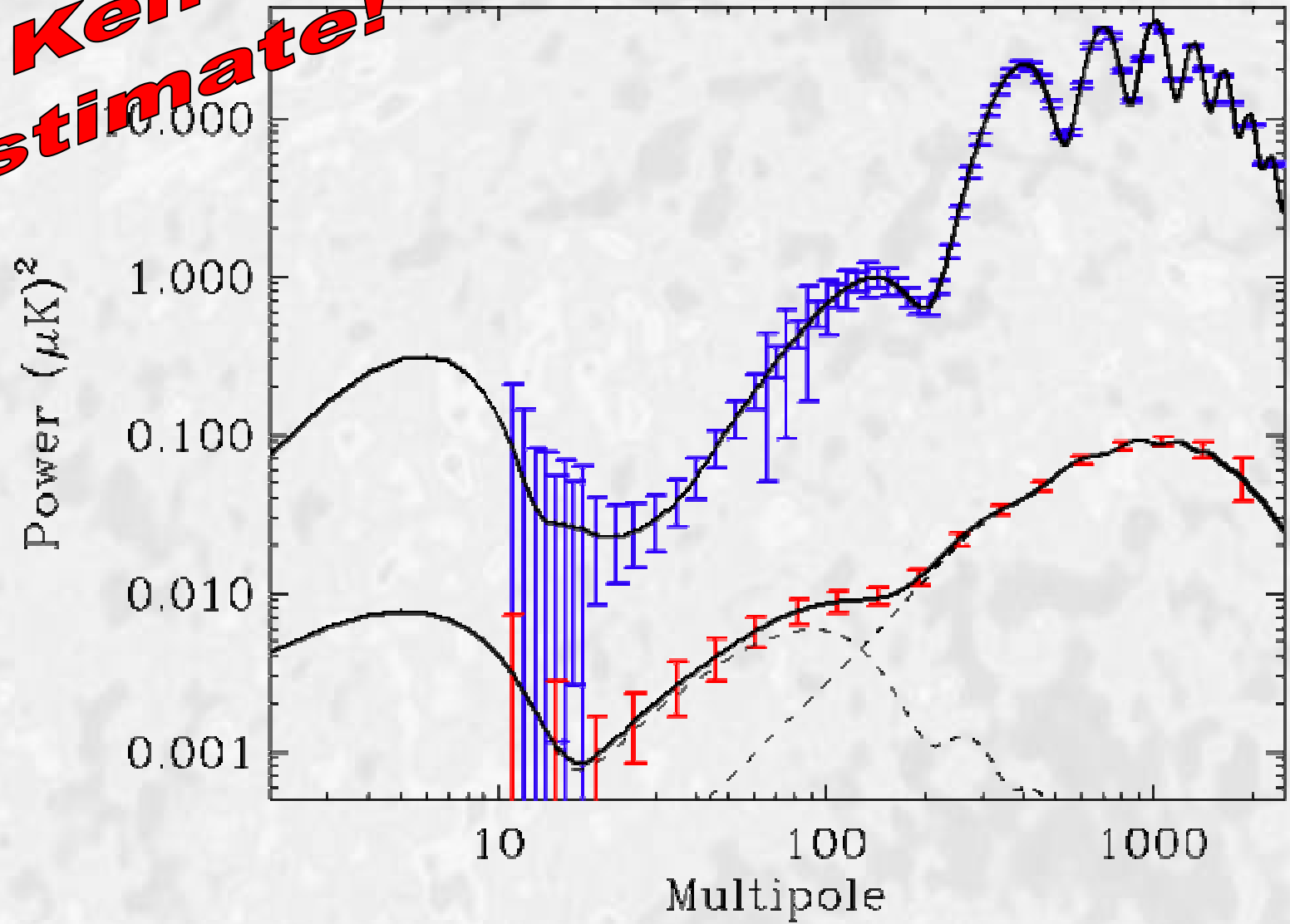
PI(s)

Reference

Web Page : <http://cfcp.uchicago.edu/~peterh/polarimetry/quiet3.html>

QUIET++

Ken's Estimate!



-
- We will have begun to reconstruct the B-B spectrum with high quality maps of the polarized microwave sky of area ~ 300 square degrees (i.e., less than a percent of the sky) and perhaps 10%.
 - All of the previous are also sold as preparatory experiments for the “next” satellite mission (post-Planck), CMBPol...

PAPPA

Alan Kogut / Goddard Space Flight Center

Primordial Anisotropy Polarization Pathfinder Array (PAPPA)

Astronomy and Physics Research and Analysis Proposal

We propose to fly the Primordial Anisotropy Polarization Pathfinder Array (PAPPA) to measure the polarization of the cosmic microwave background (CMB), characterize polarized Galactic foregrounds, and search for the imprint of gravity waves produced during an inflationary epoch in the early universe. It will characterize the E-mode polarization on angular scales comparable to the horizon at decoupling, and search for the gravity wave background produced during inflation. Measurement of the power spectrum of the dominant E-mode polarization improves understanding of fundamental cosmological parameters by breaking parameter degeneracies inherent when fitting temperature data alone. Detection of a fainter B-mode signal would have profound consequences for cosmology and high-energy physics. The amplitude of the B-mode polarization is a direct measure of the energy scale of inflation. Its detection would thus not only provide a "smoking gun" demonstration of inflation, but the determination of the relevant energy scale would shed light on physics at energies forever inaccessible to direct experimentation in particle accelerators. PAPPA addresses national priorities outlined in recent reports by the National Academy of Sciences and further detailed in the Beyond Einstein roadmap for NASA's Structure and Evolution of the Universe theme. PAPPA will develop critical technologies for the Beyond Einstein inflation probe and validate their performance in a flight environment. PAPPA is designed to minimize systematic error, and incorporates multiple features likely to be part of an eventual space mission. It consists of 32 independent "polarimeters-on-a-chip", each fabricated using photolithographic techniques with no macroscopic components other than the beam-forming optics. The polarimeters are solid state, low power, and fully scalable to large format arrays.

Long Term

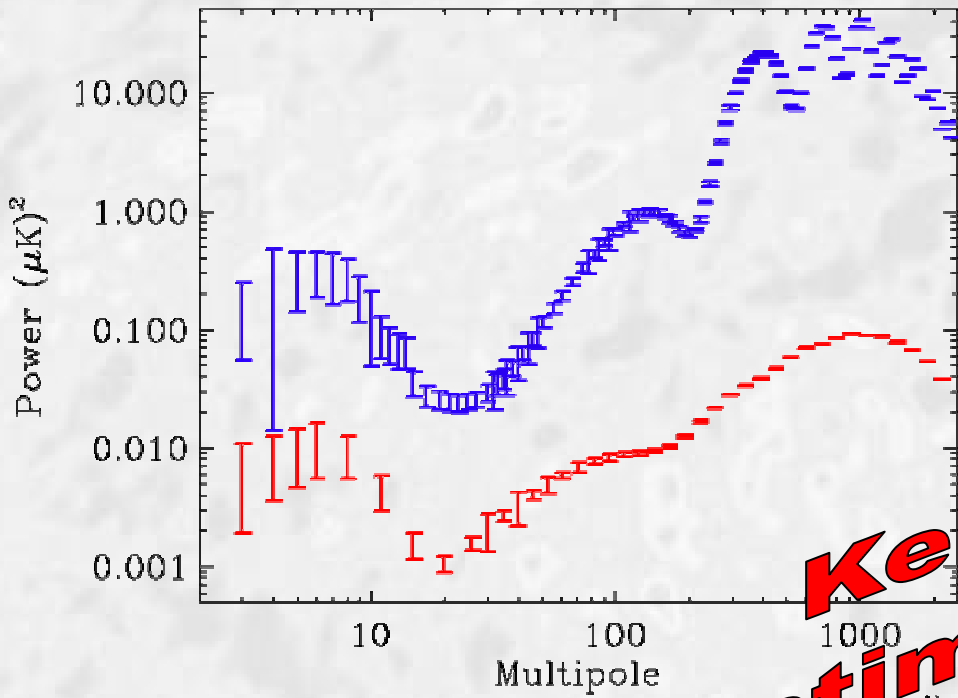
NASA's Inflation Probe Studies

- Imaging Cosmic Microwave Background Polarization with EPIC
 - Bock, James (NASA Jet Propulsion Laboratory)
- A Mission Concept Study for the Einstein Inflation Probe
 - Hinshaw, Gary (NASA/GSFC)
- Mission Concept Study for the Einstein Polarization Interferometer for Cosmology (EPIC)
 - Timbie, Peter (University of Wisconsin-Madison)
- The possibility of a European Inflation Probe is being discussed as well.

Inflation Probe Guesses

Technology :	Platform : Satellite
Frequencies : ..., ..., ..., 90, ..., ... GHz	Telescope : ~ 3m
NET/Det. : $35 \mu\text{K}_{\text{CMB}}\text{S}^{1/2} ?$	Location : L2 ?
# of Det. : 10000 ?	Start Date : 2017 ?
Beam Size : 4' (?)	Duration : 2 years ?
Multipoles : 2-2500	Sky Fraction : Full Sky
	Efficiency : 100% ?
PI(s) :	
Reference :	
Web Page :	

CMBPOL



**Ken's
Estimates**

WMAP94

