Einstein Polarization Interferometer for Cosmology (*EPIC*)

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Beyond Einstein
SLAC
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EPIC Mission Concept Study Team

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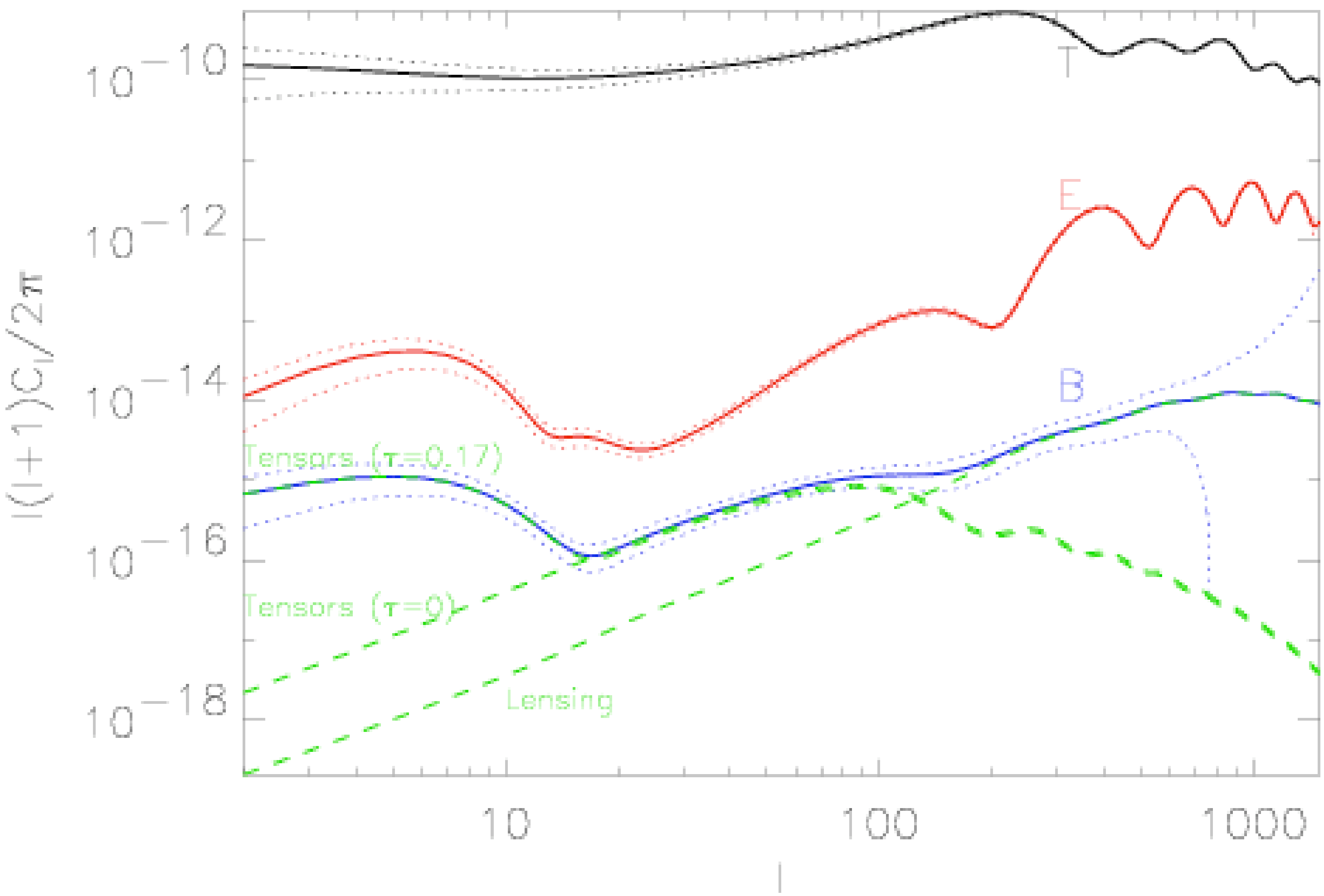
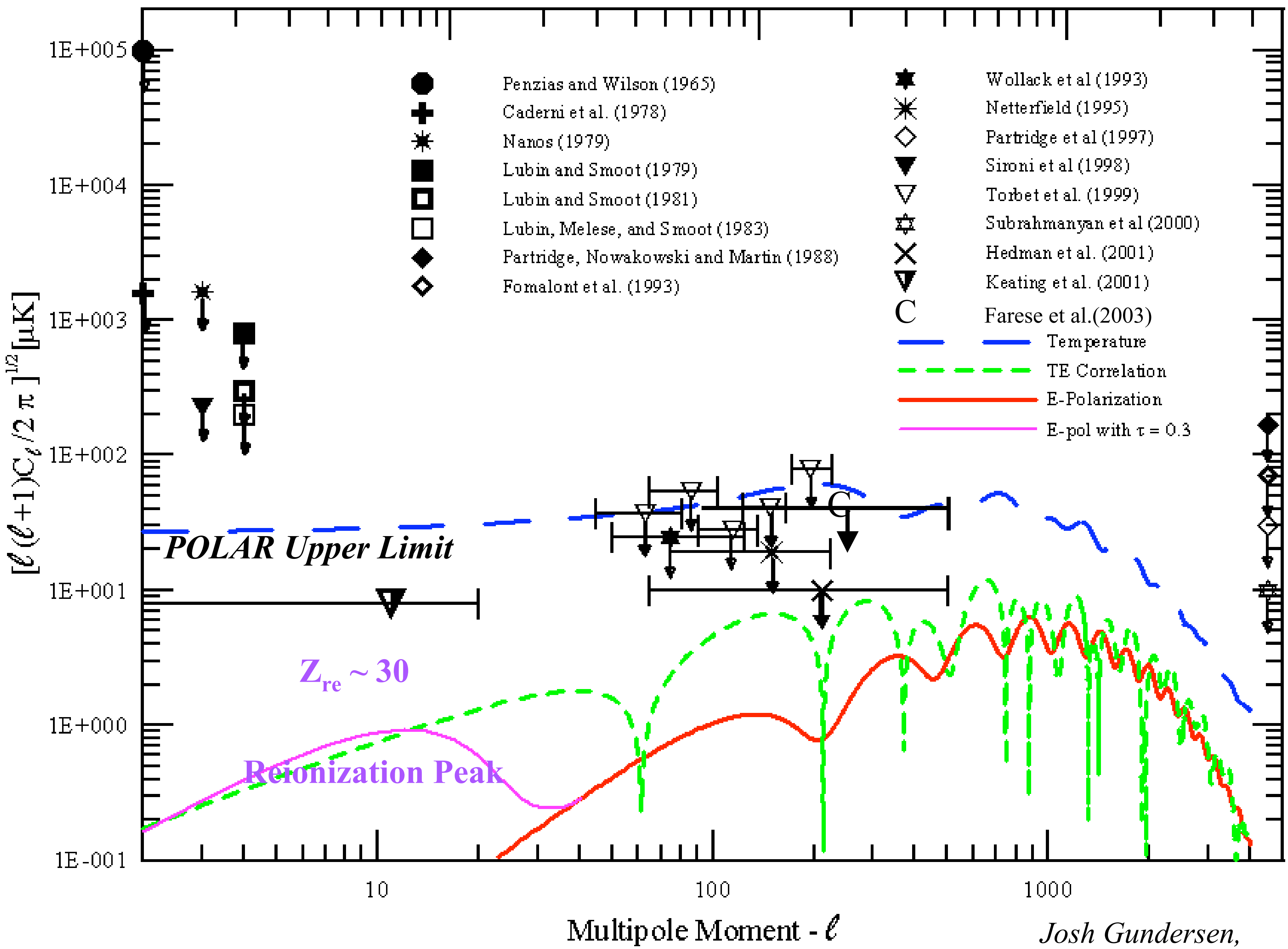
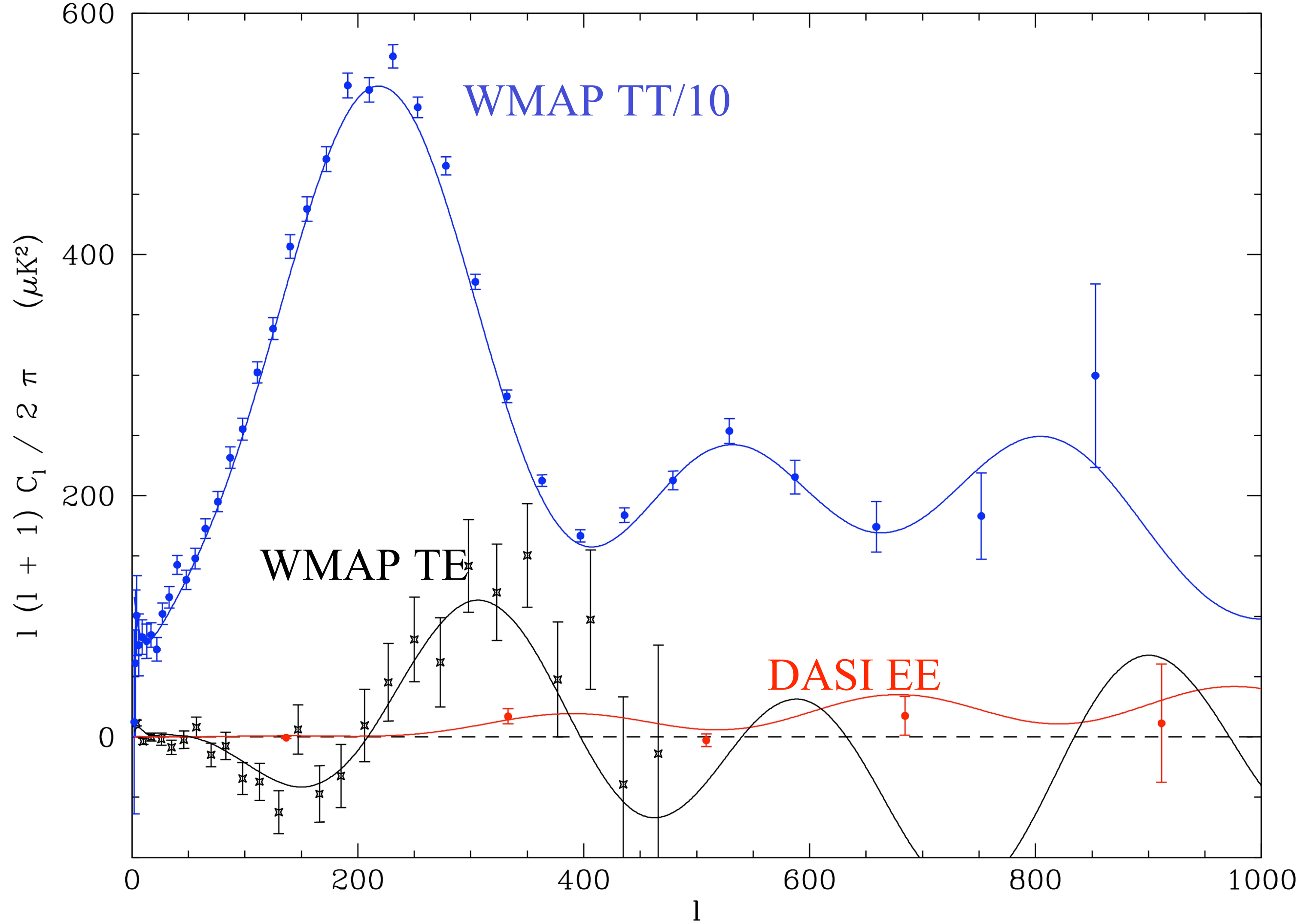
CMB Power Spectrum





Penzias and Wilson (1965)
Caderni et al. (1978)
Nanos (1979)
Lubin and Smoot (1979)
Lubin and Smoot (1981)
Lubin, Melese, and Smoot (1983)
Partridge, Nowakowski and Martin (1988)
Fomalont et al. (1993)
Wollack et al (1993)
Netterfield (1995)
Partridge et al (1997)
Sironi et al (1998)
Torbet et al. (1999)
Subrahmanyan et al (2000)
Hedman et al. (2001)
Keating et al. (2001)
C
Farese et al.(2003)
Temperature
TE Correlation
E-Polarization
E-pol with τ = 0.3
POLAR Upper Limit
Zre ~ 30
Reionization Peak
1E+005
1E+004
1E+003
1E+002
1E+001
1E+000
1E-001
10
100
1000
[ℓ(ℓ+1)Cℓ/2π]^1/2 [μK]
Multipole Moment - ℓ
Josh Gundersen,

CMB Polarization Detections!

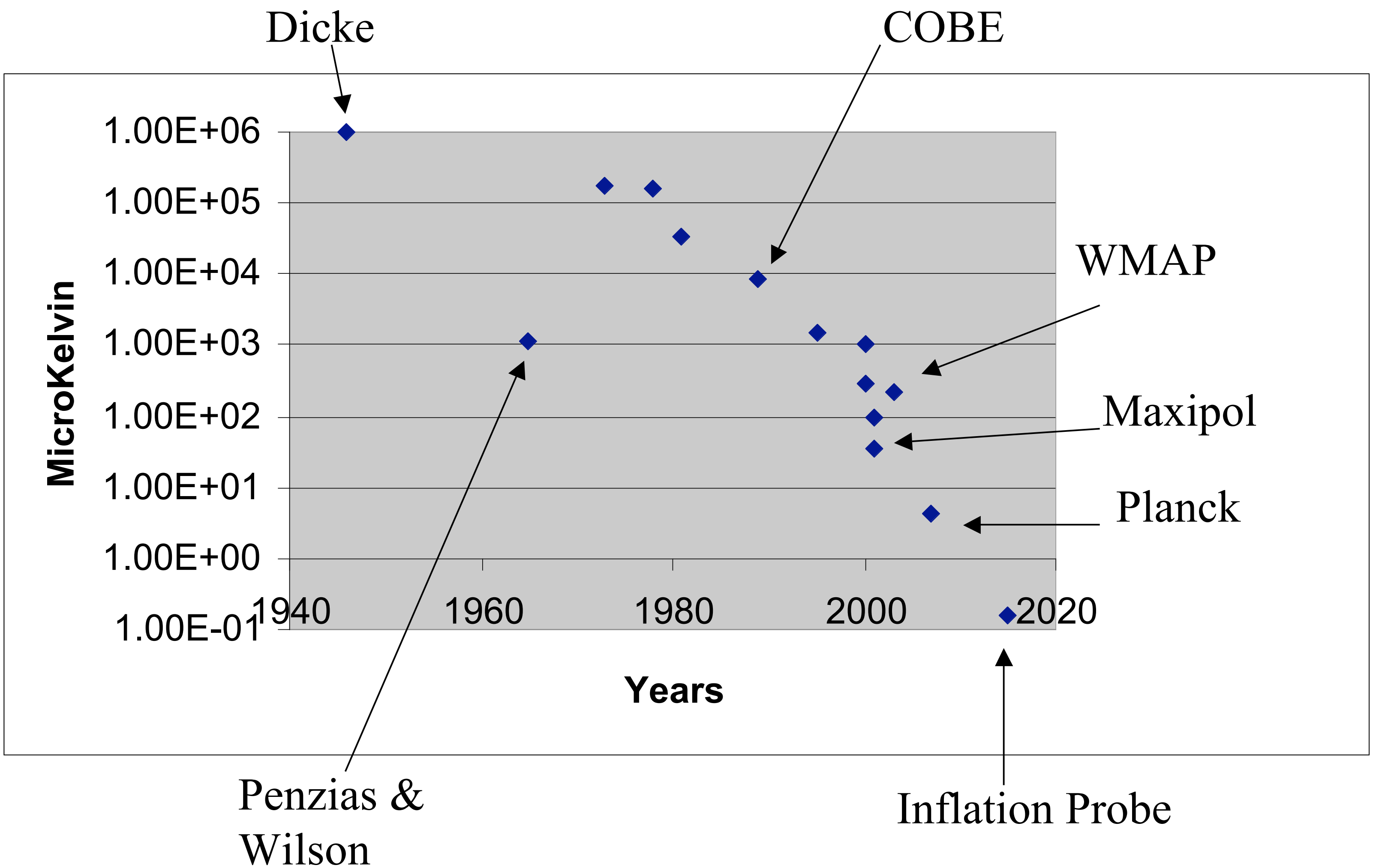


Experimental Challenges

- •Sensitivity
- •Angular resolution
- •Modulation
  - spatial “chop”
  - polarization (Q--U)
- •Atmosphere
- •Temperature stability
- •Instrumental polarization
- •Antenna sidelobes

Sensitivity of CMB Detector *Systems* vs Epoch

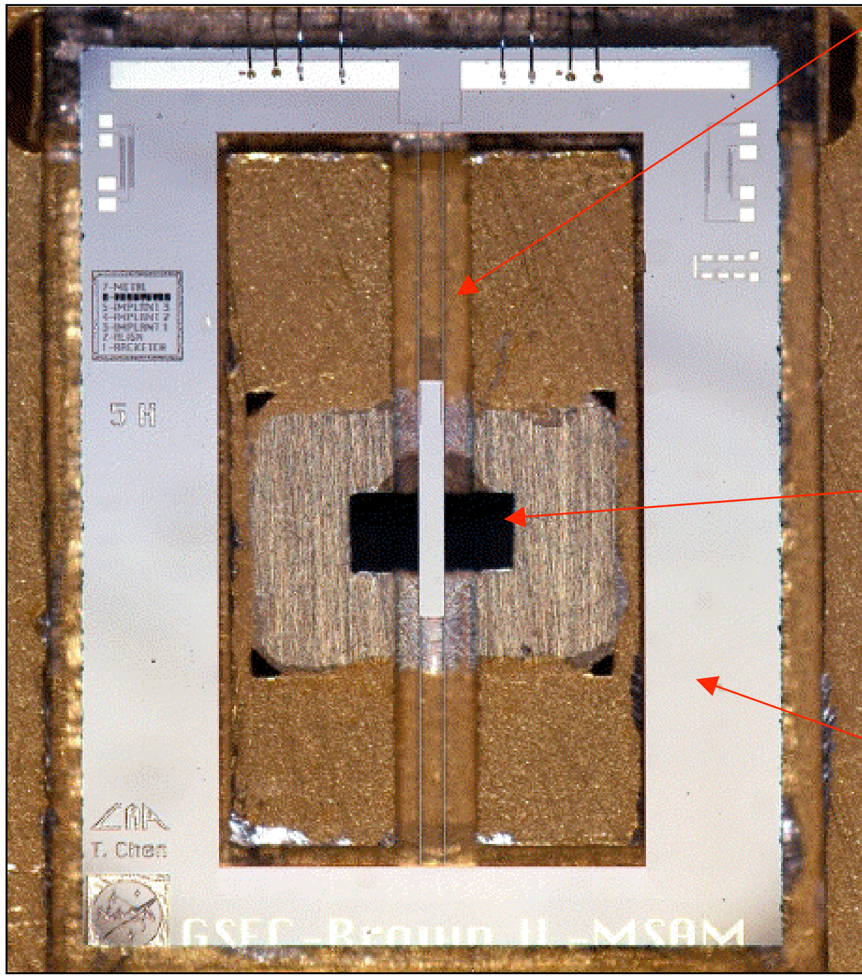
$$\Delta T_{RMS}(1s) \Big/ \sqrt{N_{Det'rs}}$$



Detectors

- bolometers are capable of reaching background limit from CMB
- cooled to < 100 mK
- superconducting transition-edge thermistors (TES)
- readout with SQUID multiplexers

micromachined Si legs



waveguide x-section

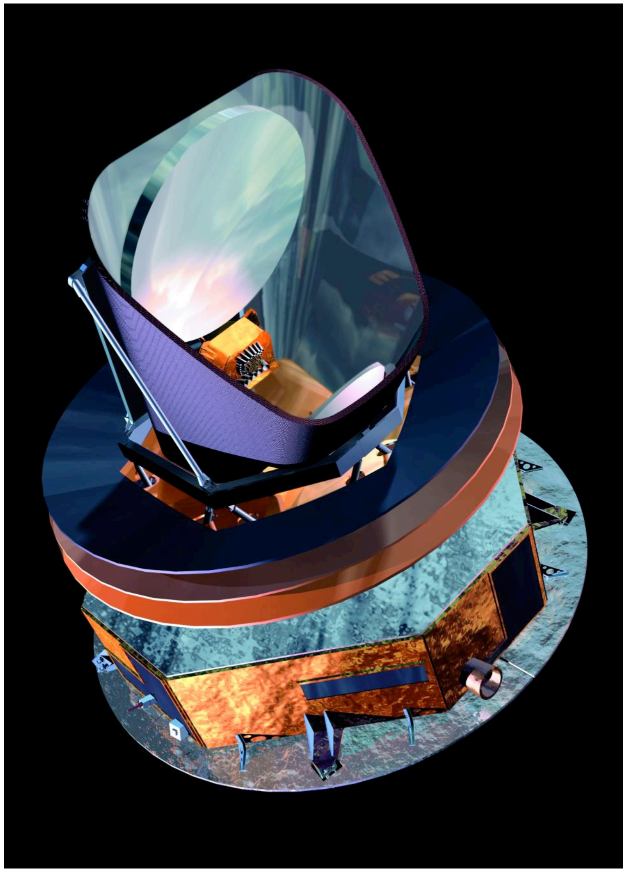
Si frame at 100 mK

Waveguide-coupled bolometer from MSAM balloon-borne telescope

Angular Resolution

PLANCK telescope

DASI interferometer



Why use an interferometer for CMB?

Systematics!

- simple optics – no reflectors, which can polarize light
- correlation measurement is stable, measures Stokes U directly on a single detector (no differencing)
- instantaneous differencing of sky signals without scanning
- angular resolution ~ 2X better than filled dish of same dia
- measures both Temp and Polarization anisotropy

Stokes Parameters

For a linearly polarized wave,

$$\vec{E} = E_x \hat{e}_x + E_y \hat{e}_y \quad \text{where} \quad E_{x,y} = a_{x,y} e^{i(kz - \varpi t)}$$

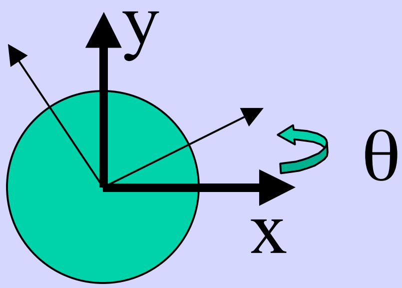
$$I = E_x^2 + E_y^2$$

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

$$U = 2E_x E_y$$

Stokes parameters are:
-additive
-coordinate-dependent

Consider rotations:

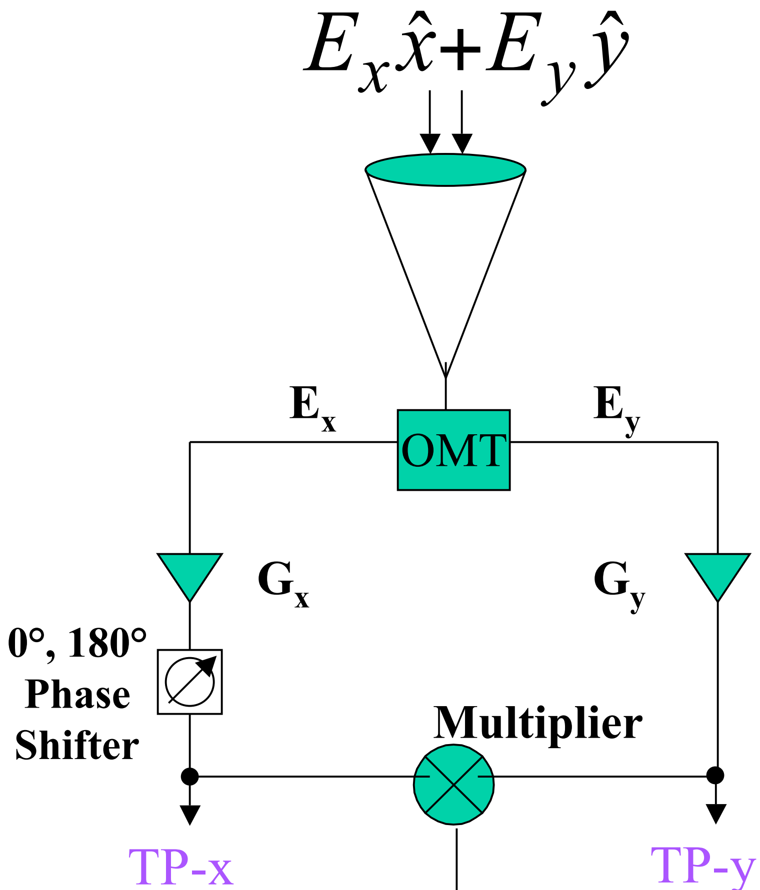


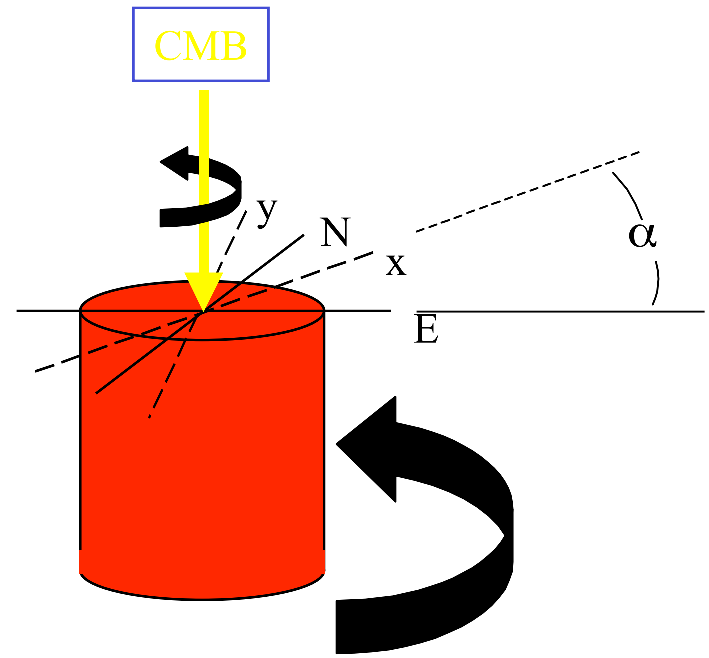
$$\begin{pmatrix} E_{x'} \\ E_{y'} \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

Example: for $\theta = \pi/4$

$$E_{x'}^2 - E_{y'}^2 = 2E_x E_y = U$$

The Spinning CorrelationPolarimeter



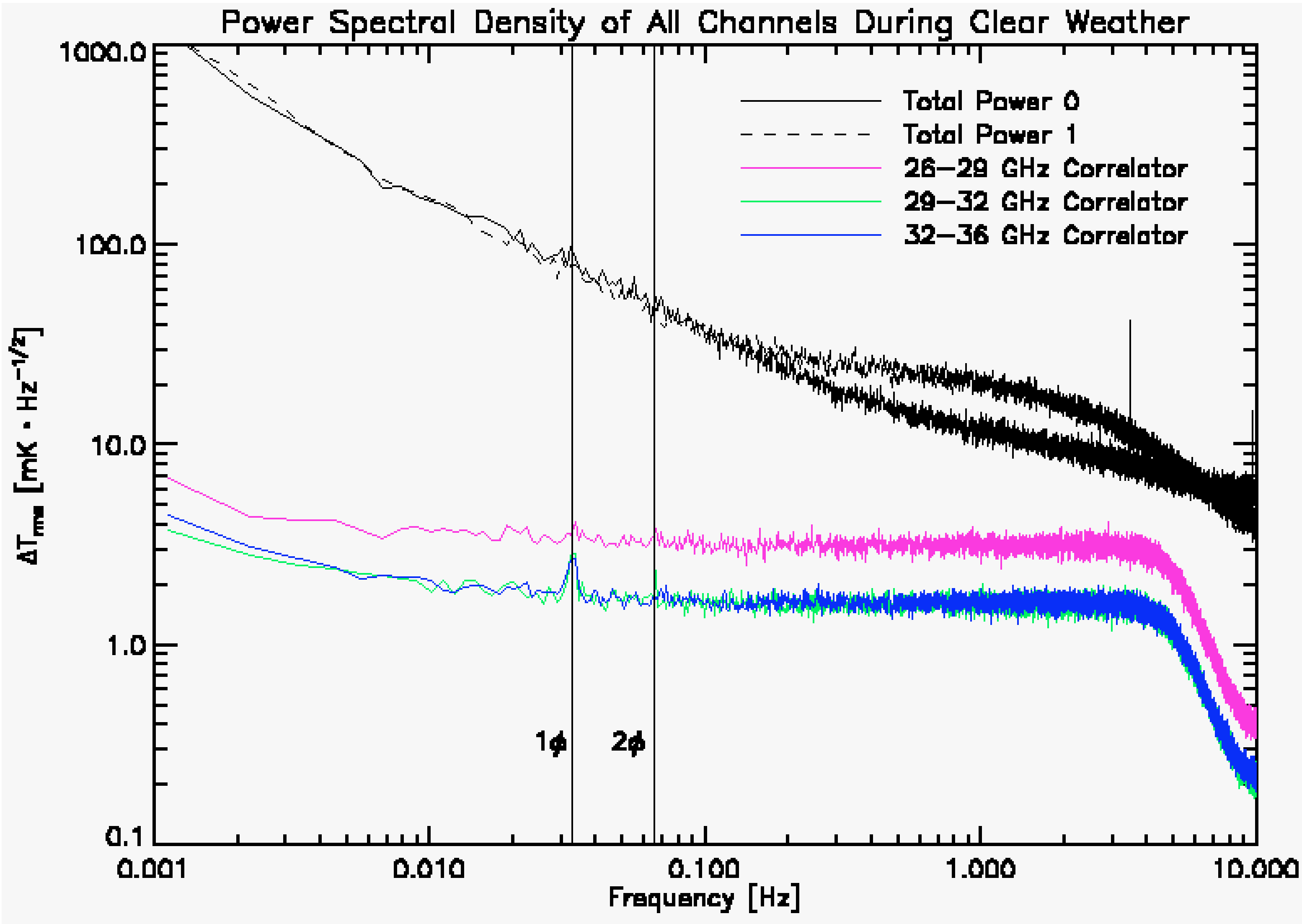


$$Output \propto E_x \times E_y$$

$$\propto \pm E_{x0} E_{y0} G_x G_y U$$

$$Signal = Q \cdot (\cos 2\alpha) + U \cdot (\sin 2\alpha)$$

Correlation Polarimeter



Ryle's Phase-switching Interferometer (1952)

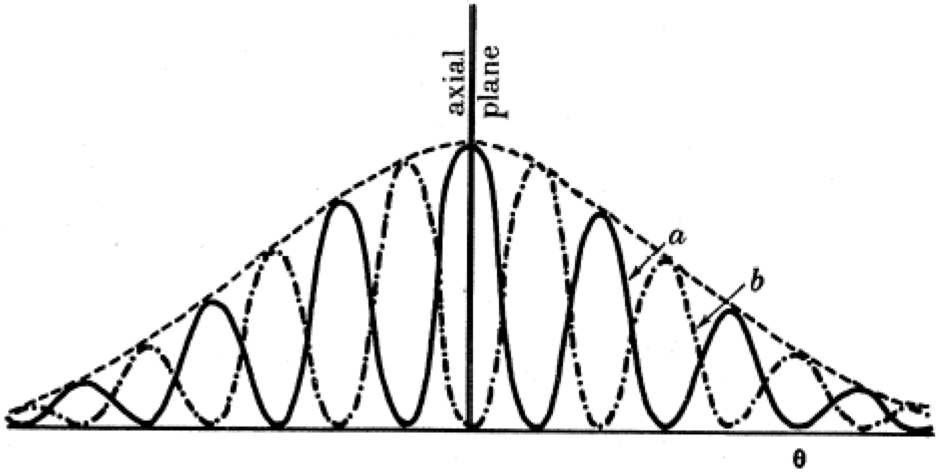


FIGURE 1. Reception pattern of two spaced aerials: (*a*) connected in phase and (*b*) connected in anti-phase.

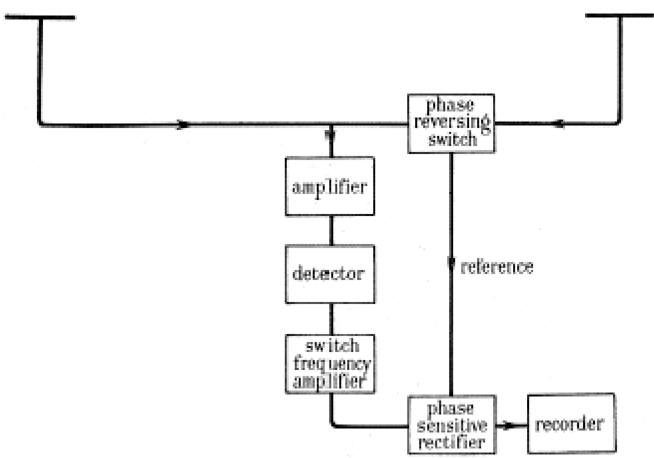


FIGURE 2. Block diagram of the phase-switching system.

Correlation of signal from 2 antennas

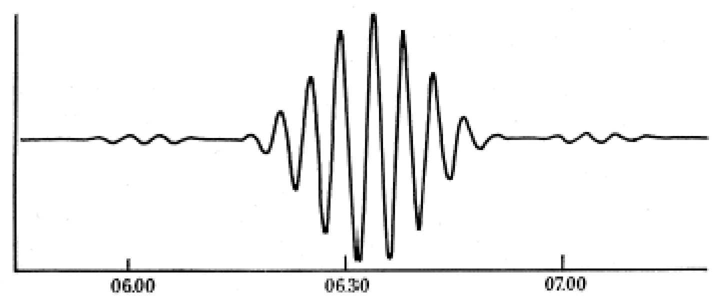
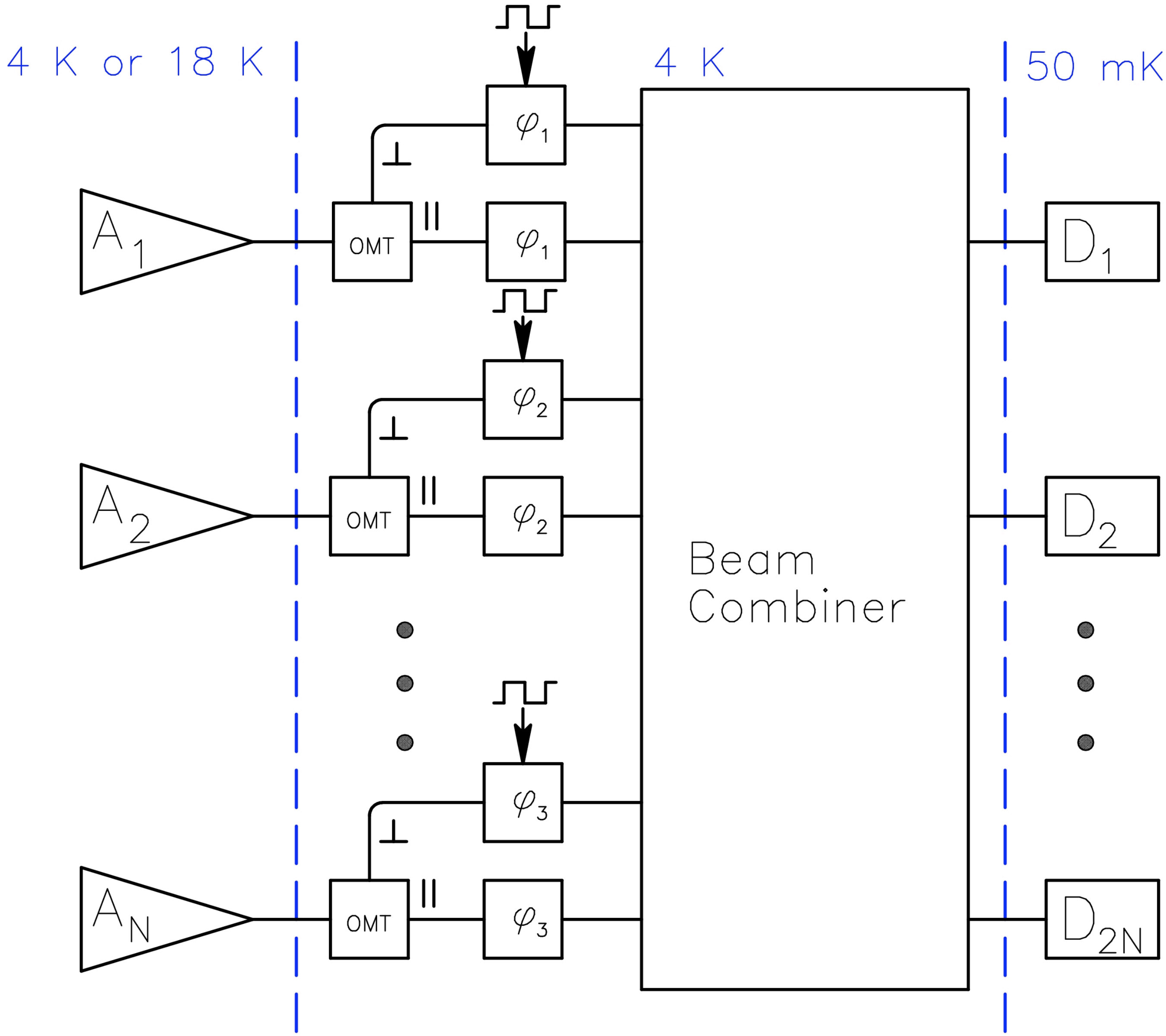
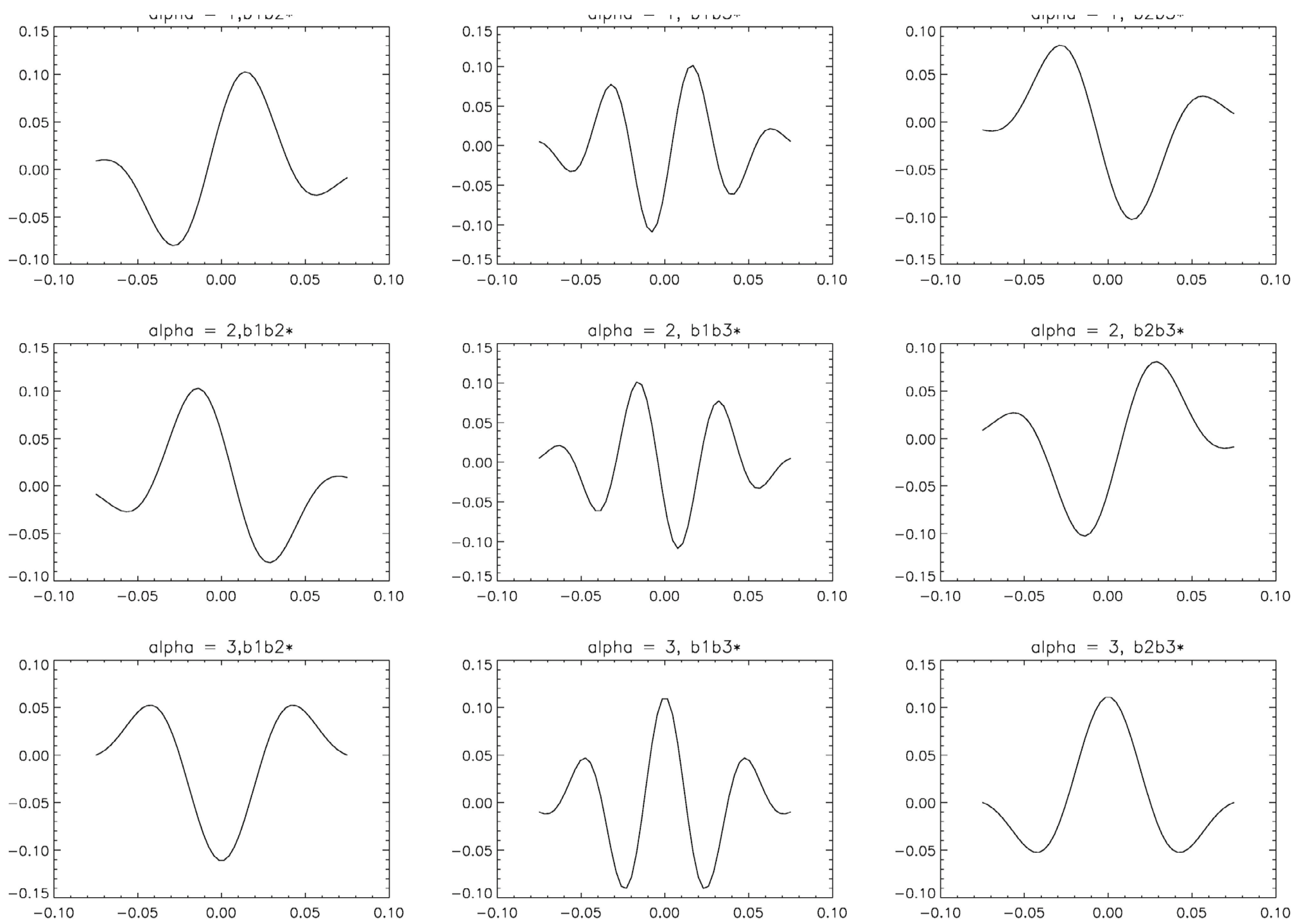


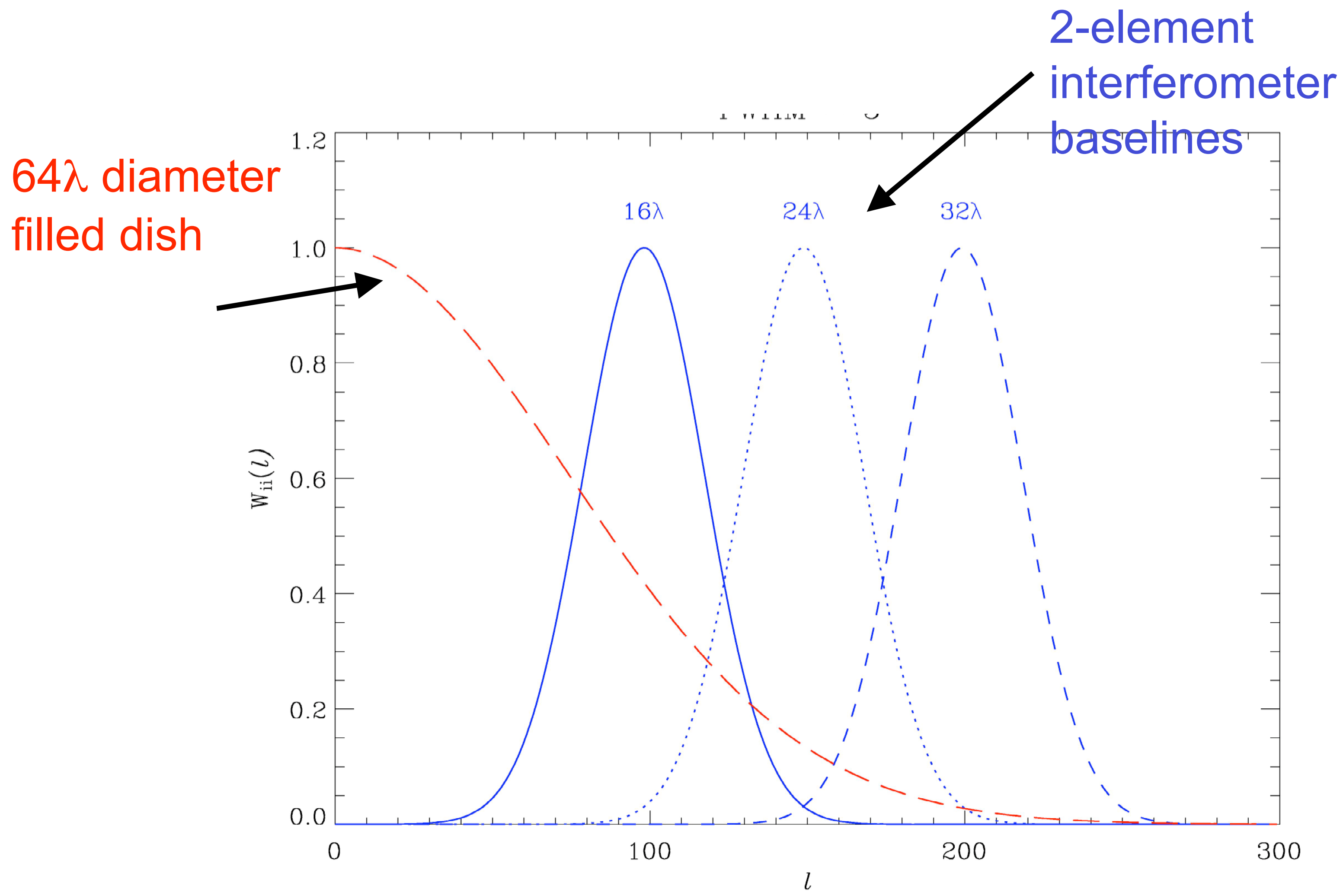
FIGURE 3. Record of the intense radio star in Cassiopeia obtained with the phase-switching system on a wave-length of 3·7 m.


4 K or 18 K
4 K
50 mK
A1
A2
AN
OMT
OMT
OMT
⊥
||
φ1
φ1
φ2
φ2
φ3
φ3
Beam Combiner
D1
D2
D2N

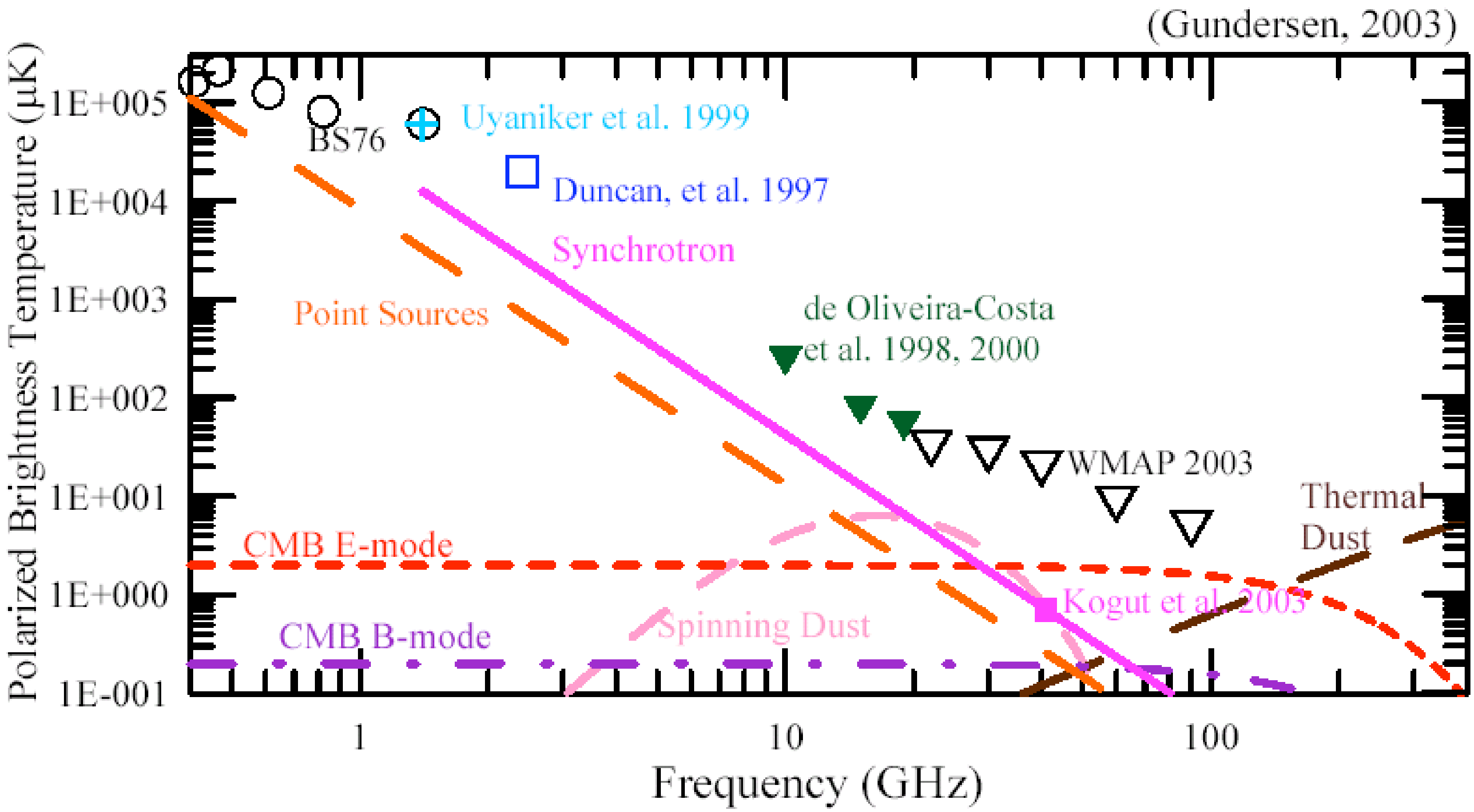
3-Element Interferometer Angular Response Functions



Window Functions



Polarized Foregrounds



EPIC Overview

•Goal 1: measure gravitational waves from inflation

•Goal 2: measure gravitational lensing of CMB

•4-year mission, observe full sky 2X per year

•> 6 frequency bands for foreground removal

•Multiple interferometric arrays (>2) at each wavelength for l-space ranges covering l = 2 to >400

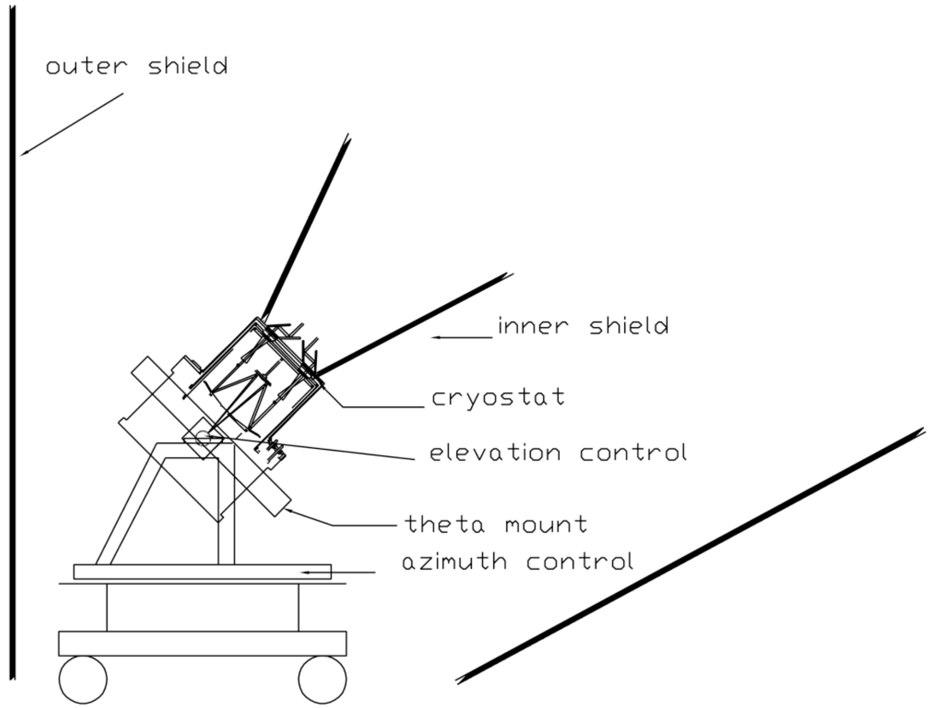
•Measures Stokes I, Q, U interferometrically for l > 40,
directly for l < 40

•Bolometric (TES) detectors (> 2700) cooled to ~ 50 mK

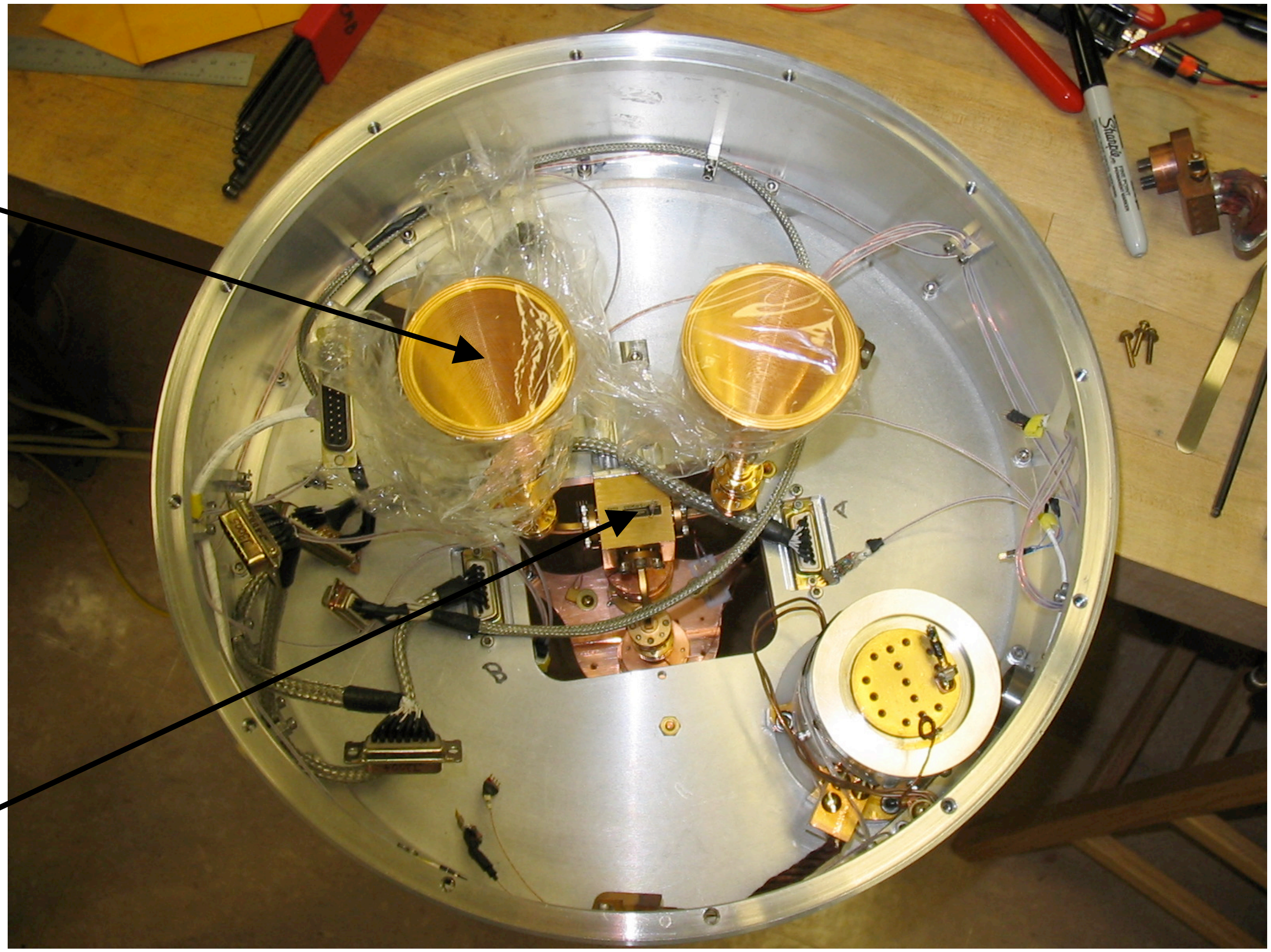
•Multiplexed SQUID readout

The Millimeter-Wave Bolometric Interferometer (MBI)

- 8 feedhorns (23 baselines)
- 90 GHz (3 mm)
- ~1° angular resolution – search for B-mode pol'n
- 7° FOV
- under construction, first light expected winter 2005
- White Mountain, CA (13,500 ft)



Single-Baseline Test



EPIC Mission Concept Study Tasks

- Sensitivity analysis
- Optimize l-space coverage of arrays
- Optimize frequency coverage for foregrounds (WMAP, Planck, etc. results are key)
- Beam combiner
- Phase shifters
- Data analysis/simulations of aperture synthesis
- Cryogenics