The Einstein Polarization Interferometer for Cosmology (*EPIC*)

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for the *EPIC* collaboration

EPIC Mission Concept Study Team

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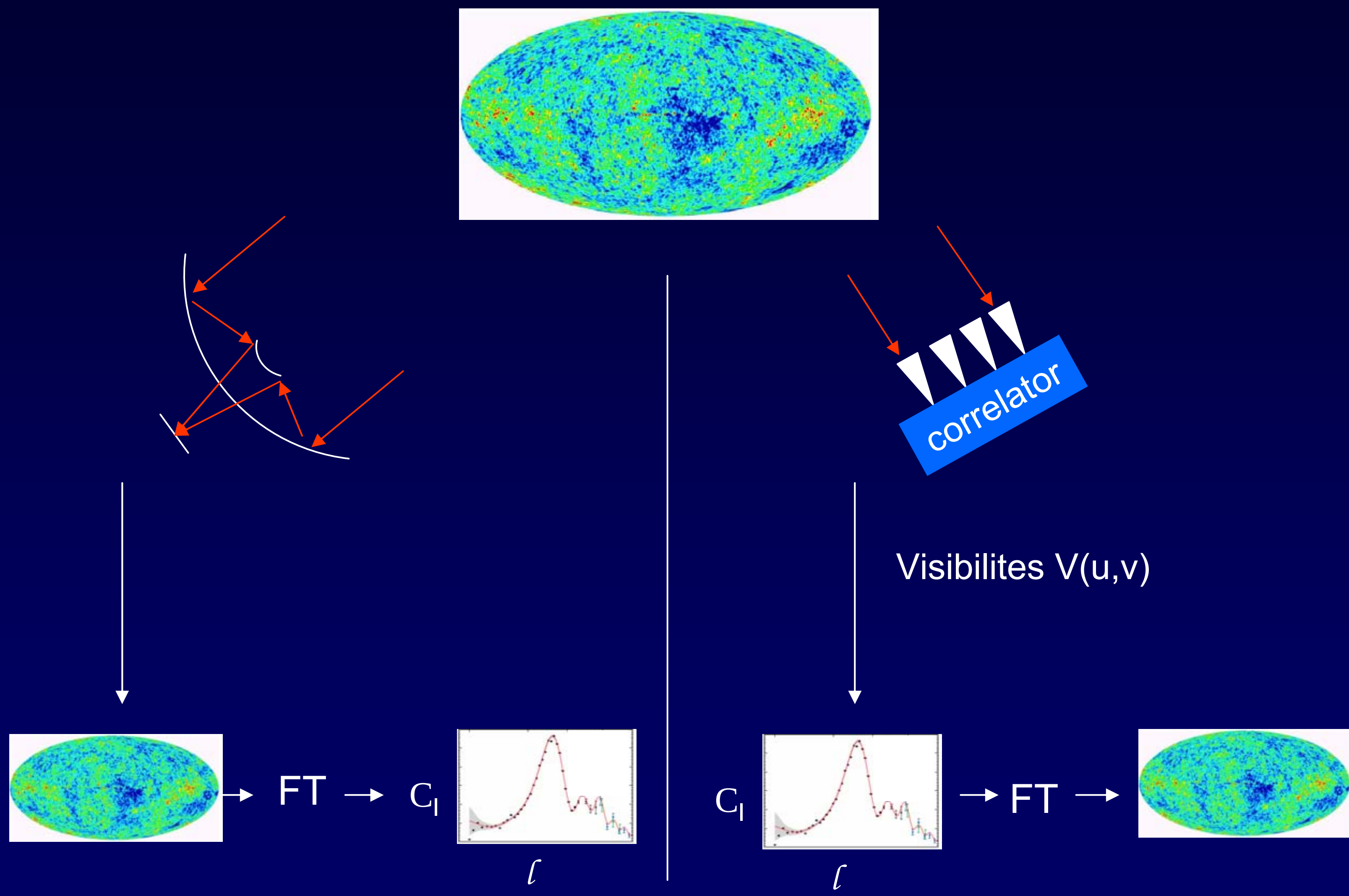
Imaging *vs* Interferometry



CMB Interferometers

	ν (GHz)	FOV	# ant’s	receivers
DASI	30	5^{o}	13	HEMT
CBI	30	44’	13	HEMT
MINT	150	30’	4	SIS
VSA	30	7^{o}	14	HEMT
BIMA	30	6’	6	HEMT
OVRO	30	4’	9	HEMT

Need to extend to more frequencies & more receivers (modes)

Why use an interferometer for CMB? (1)
Systematics

- Simple optics - form beams with corrugated horn arrays
  - Symmetric beam patterns
  - Low sidelobes
  - No polarization or emission from mirrors

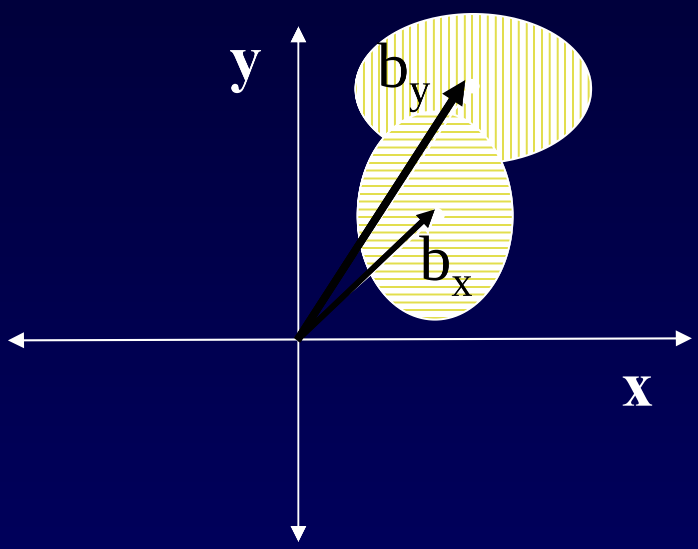
- Field-of-view determined by beamsize of array elements (no beam distortions off-axis)

Why use an interferometer for CMB?(2)

- Stability of correlation measurement; Stokes U measured directly on single detectors (no differencing of detectors)
- Instantaneous differencing of sky signals without scanning
- Measures power spectrum directly
- Measures both temperature and polarization anisotropy
- Coherent or incoherent receivers/detectors possible
- Angular resolution

Polarimeter Systematics: Beam Errors

- Beam ellipticity
- Relative pointing: $\mathbf{b}_x \neq \mathbf{b}_y$
- Cross-polar: x couples to y …
- Sidelobes
- Polarization angle



Beam Systematics

	bad	worse	worst
Approach	$Q \leftrightarrow U$ ($E \leftrightarrow$ B)	$\Delta T \rightarrow Q,U$ ($\Delta T \rightarrow E,B$)	$T \rightarrow Q,U$ ($T \rightarrow E,B$)
Power difference	cross-talk	mismatched beam mismatched pointing	gain errors
Interfere linear polarizations	cross-talk	cross-talk cross-polar beam	OK!
Interfere circular polarizations	gain errors	cross-talk cross-polar beam	OK!

Challenges for Interferometry

- Correlate signals from N antennas
- Beam combiner - scalable, low loss
- Arrays from 30 to 300 GHz

Ryle's Adding Interferometer (1952)

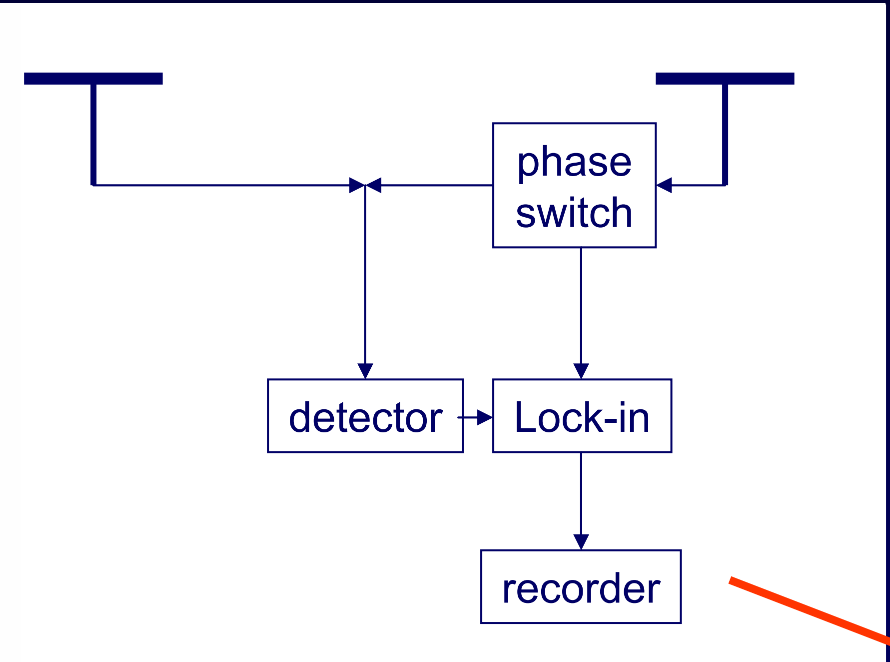


Figure 2. Block diagram of the phase-switching system.

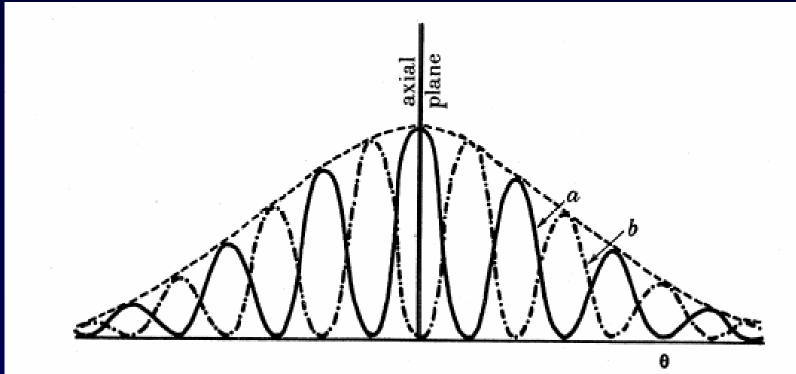


Figure 1. Reception pattern of two spaced aerials: (a) connected in phase and (b) connected in anti-phase.

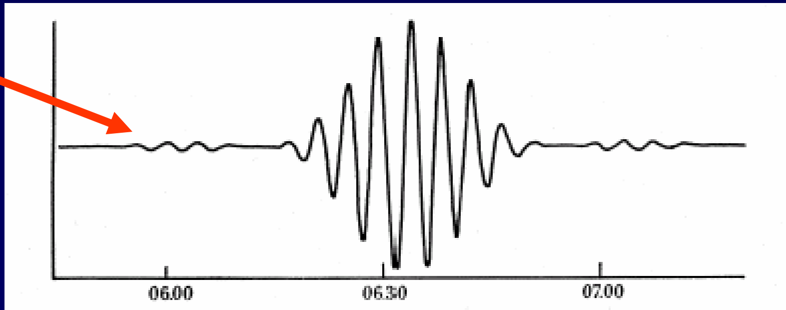
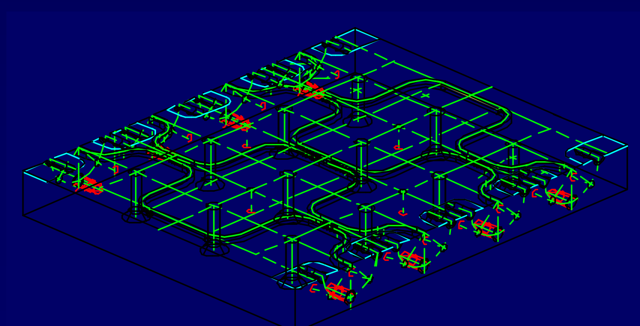


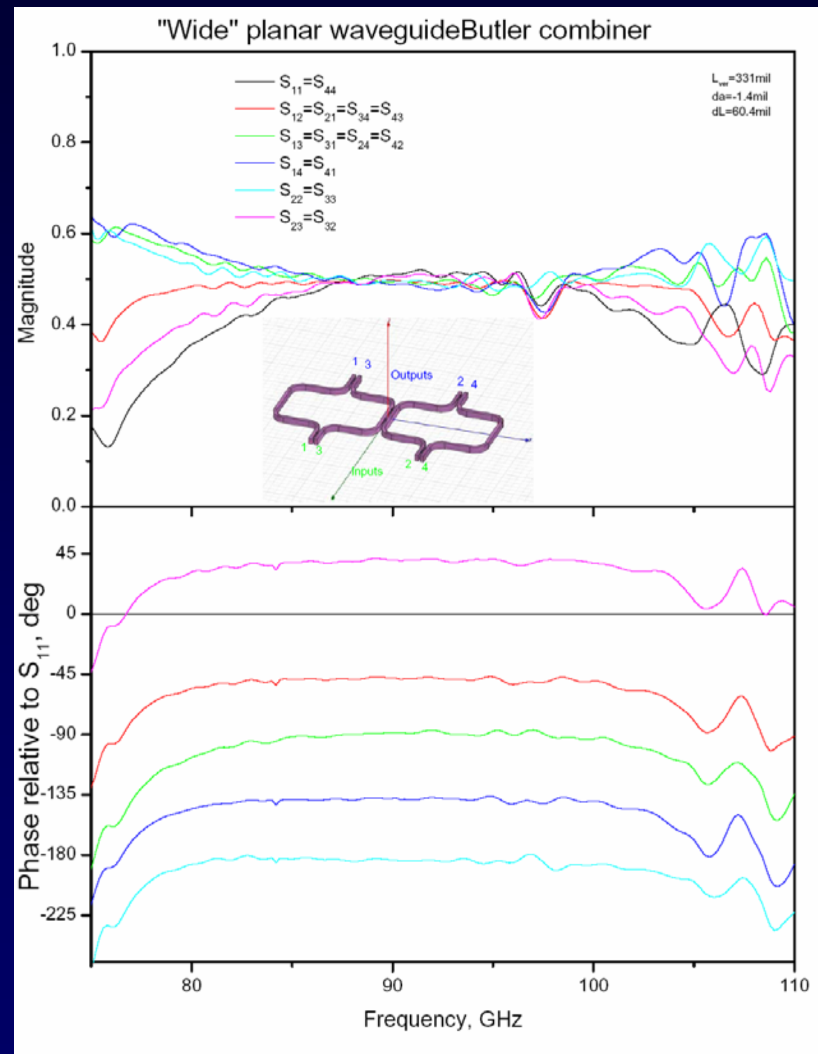
Figure 3. Record of the intense radio star in Cassiopeia obtained with the phase-switching system on a wave-length of 3·7 m.

Beam Combination

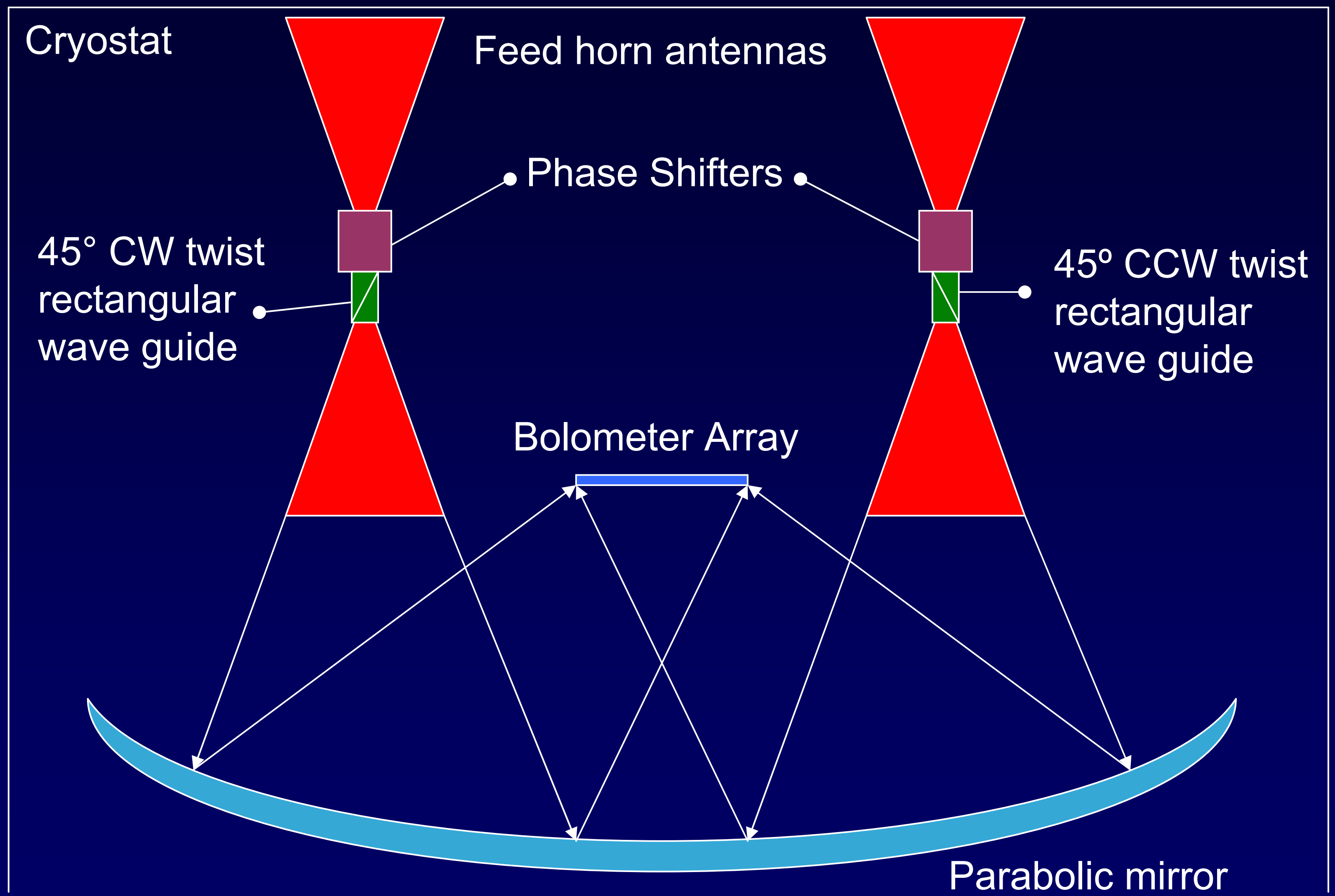
- Michelson: signals are split and combined pairwise
- Fizeau: signals from all antennas appear at all detectors
- Fizeau approach has lower noise in background-limited case, in low *n* limit, Zmuidzinas (2003)
- We are considering two Fizeau approaches:
  - Guided waves - Butler combiner (waveguide or μstrip)
  - Quasioptical combiner using a telescope

Waveguide Beam Combiner





Quasioptical Beam Combiner



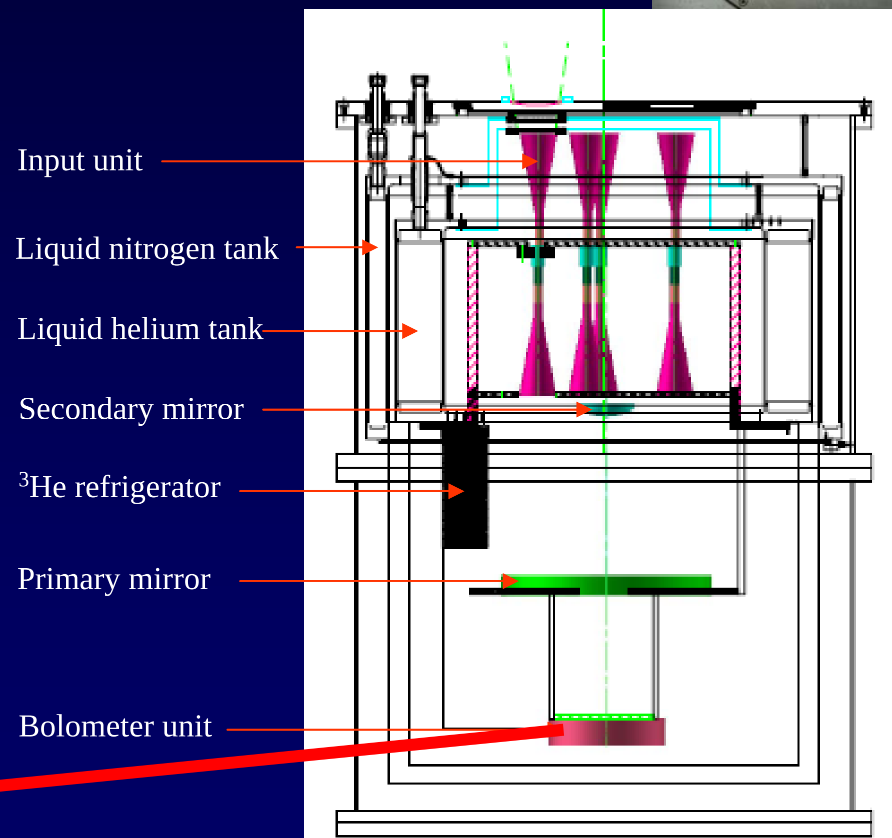
The Millimeter-Wave Bolometric Interferometer (MBI)

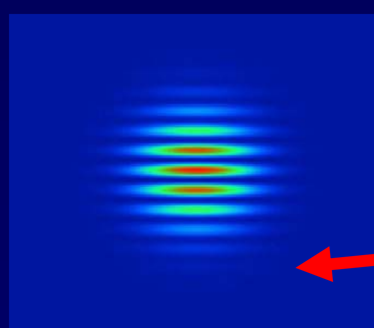
- Four feedhorns

  (six baselines)
- 90 GHz (3 mm)
- Fizeau (optical) beam combiner
- ~1° angular

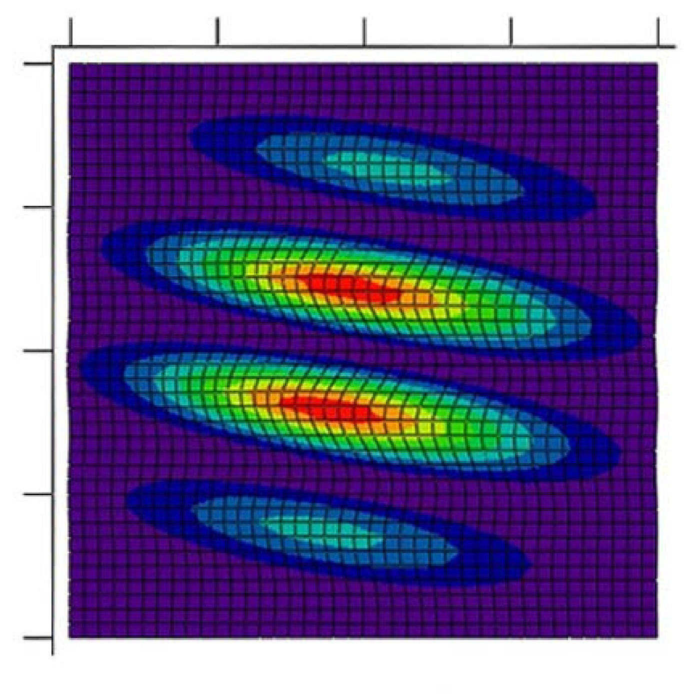
  resolution – search for

  B-mode polarization
- 7° FOV



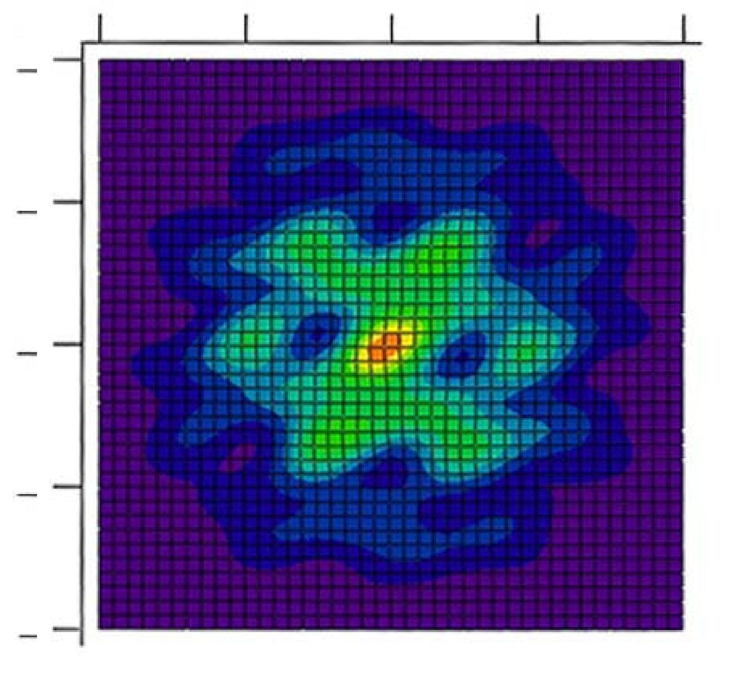


Effect of Phase Shifting



Single Baseline

(Two feeds)

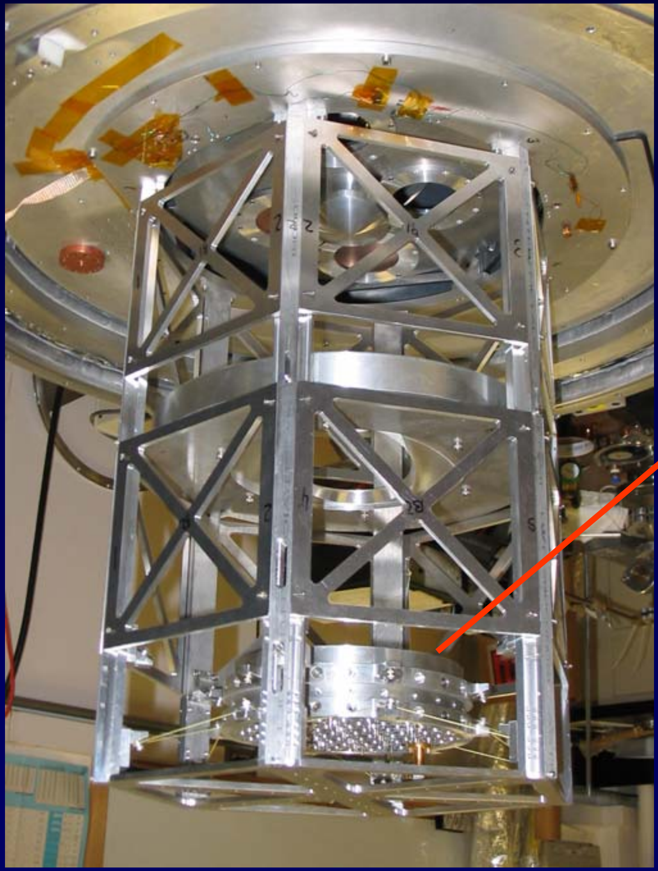


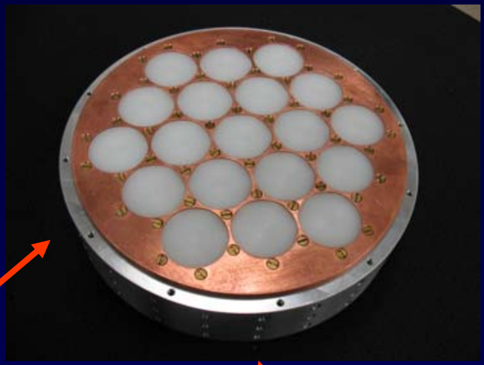
Six baselines

(Four feeds)

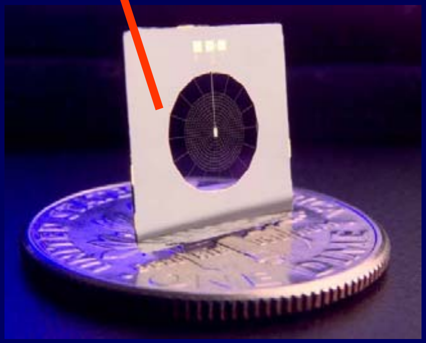
MBI Assembly

first light expected 2006
(Madison WI)





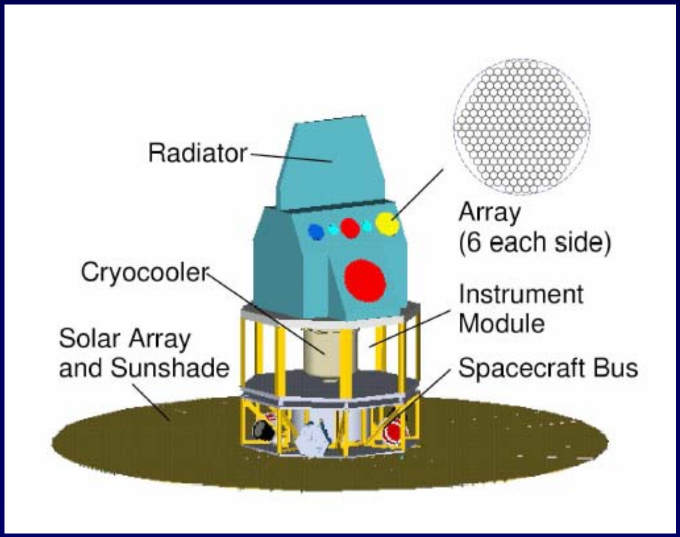
15 cm



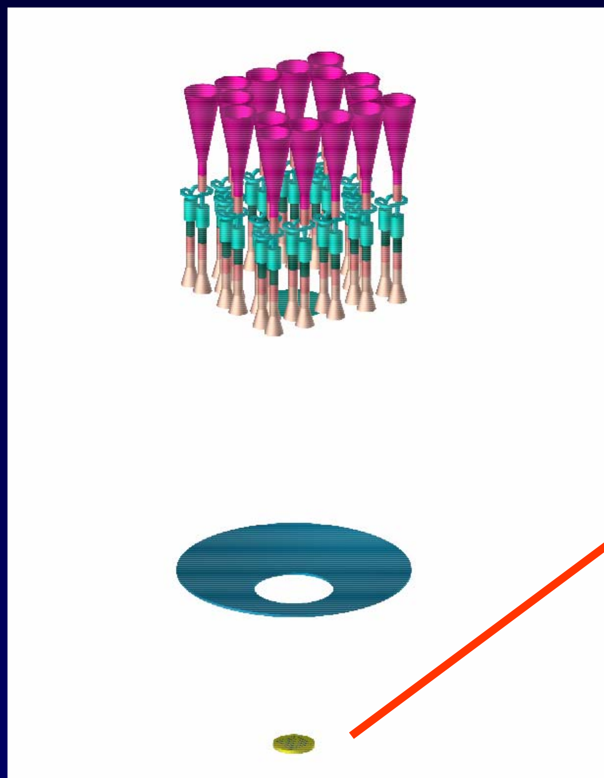
19 spider-web bolos (JPL)

EPIC Mission Concept (1)

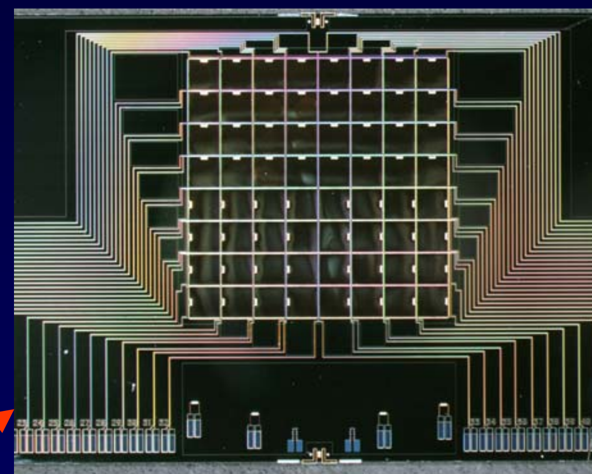
- Measure CMB *E* and *B* mode polarization over full sky to foreground limit
- Interferometer: signals cross-correlated
  - between horns: *N(N-1)/2* visibilities
  - between 2 polarizations for each horn: "correlation polarimetry"
- Close-packed arrays of *N* ~ 64 corrugated horn antennas
- Multiple arrays at multiple frequencies
- 30 GHz - 300 GHz
- ~15^{o} FOV, ~ 1^{o} synthesized beam
- Total # horns *N* ~ 1000 (= # modes)



EPIC Mission Concept (2)



16-element module



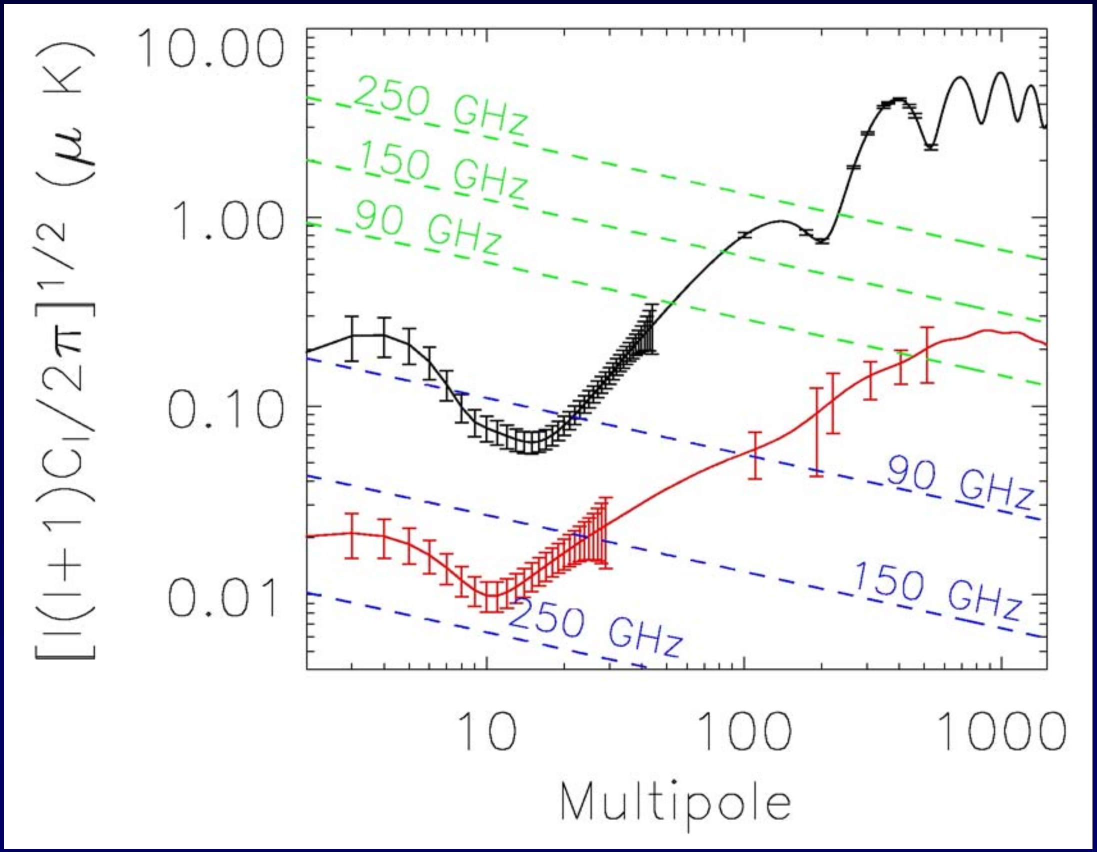
Bolometer Under Grid (BUG) TES array (NASA/GSFC)

EPIC Mission Concept (3)

- Adding interferometer
- Visibilities recovered using phase modulation
- Beam combiner/correlator: quasioptical or guided-wave
- Sensitivity comparable to filled-dish measuring *N* modes
- Full-sky coverage from L2
- Mission lifetime > 1 year

EPIC sensitivity

- 960 horns
- 90, 150, 220 GHz
- 1 year observing
- T/S = 0.01



Detector Requirements

- Multiple arrays of ~ 256 bolometers each (4 x N)
- Background-limited in space
- Time constant < 1 mS
- Several coupling schemes possible

  -Butler combiner: μ-strip or waveguide-coupled

  -Quasioptical combiner: horn coupled, planar antenna, or direct absorber
- Could use coherent (HEMT) amplifiers instead

EPIC Mission Concept Study Tasks

- Sensitivity analysis
- Optimize l-space coverage of interferometer arrays
- Data analysis
    - Analysis pipeline, simulations
    - Mosaicking over full sky
- Foreground removal - Fourier vs map space
- Beam combiner study - optical vs guided wave
- Phase shifter study - review available technology

EPIC Publications

Timbie, P. T., Tucker, G. S., Ade, P. A. R., Ali, S., Bierman, E., Bunn, E. F., Calderon, C., Gault, A. C., Hyland, P. O., Keating, B. G., Kim, J., Korotkov, A., Malu, S. S., Mauskopf, P., Murphy, J. A., O'Sullivan, C., Piccirillo, L, and Wandelt, B., D. "The Einstein Polarization Interferometer for Cosmology (*EPIC*) and the Millimeter-wave Bolometric Interferometer (MBI)," to be published in New Astr. Rev. (2007)

Korotkov, A. L., Kim, J., Tucker, G. S., Gault, A., Hyland, P., Malu, S., Timbie, P. T., Bunn, E. F., Keating, B., Murphy, A., O'Sullivan, C., Ade, P. A. R., Calderon, C., and Piccirillo, L. "The Millimeter-wave Bolometric Interferometer," SPIE 6269, (2006).

Bunn, E. F. "Systematic Effects in CMB Interferometry," submitted to Phys. Rev. D. (2006).

Bunn, E. F. and White, M. "Mosaicking in Full-Sky Interferometry," submitted to Ap. J. (2006).