The Einstein Polarization Interferometer for Cosmology (*EPIC*)

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for the *EPIC* collaboration

EPIC Mission Concept Study Team

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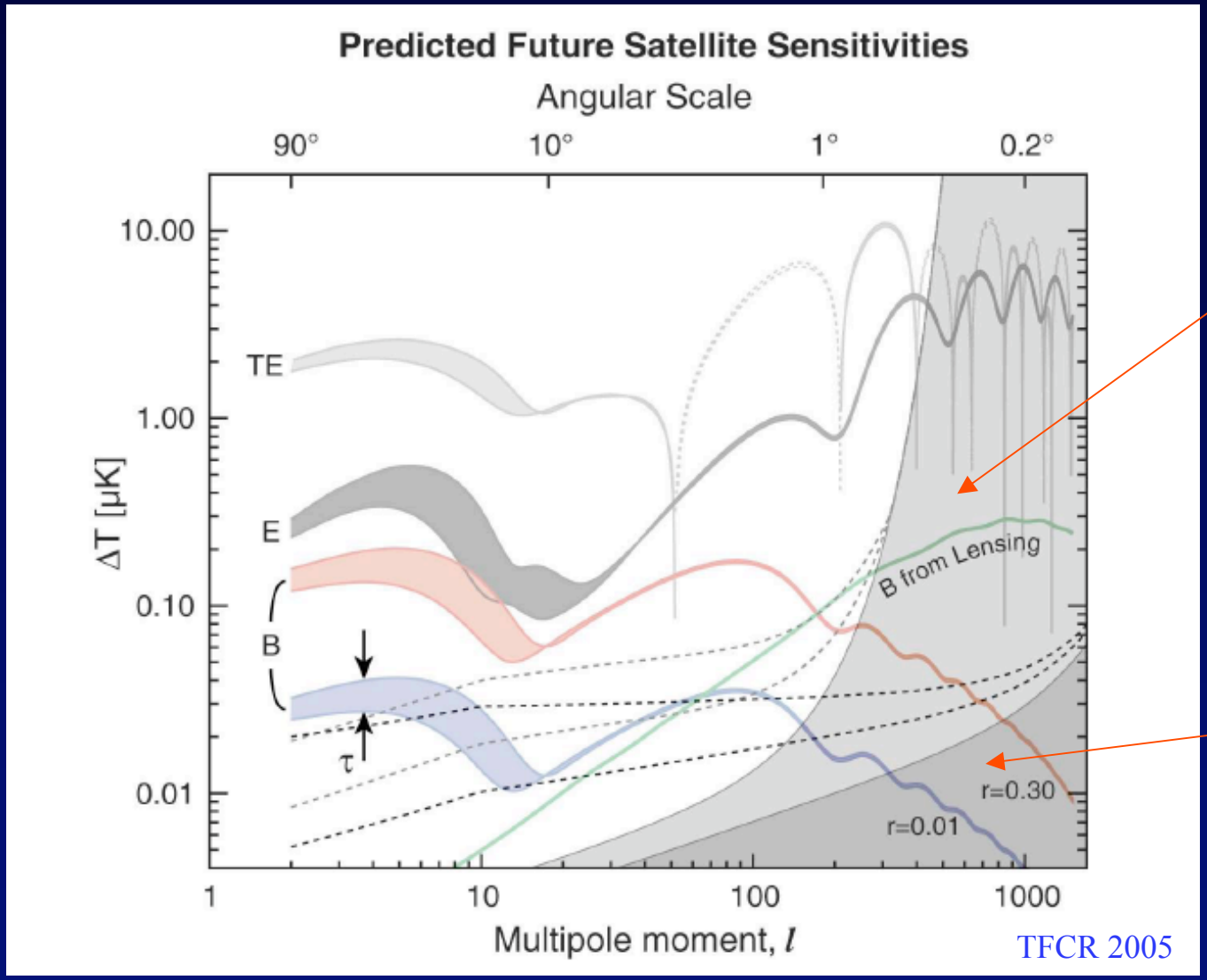
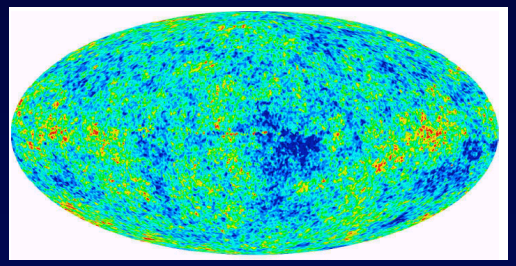


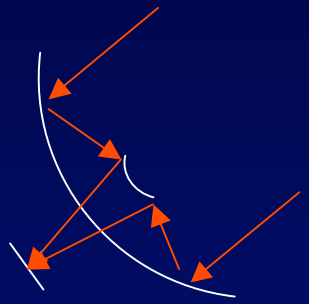
1 year in space
background-limited

1000 pixel instrument
1^0 resolution

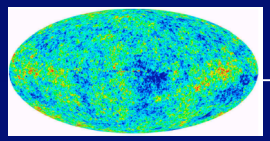
2000 pixel instrument
0.1^0 resolution

Imaging and Interferometry

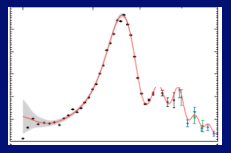




Visibilites V(u,v)



FT → C_l



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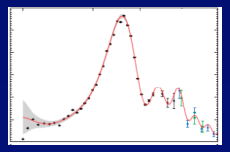

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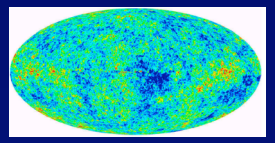


CMB Interferometers

	ν (GHz)	FOV	# ant's	receivers
DASI	30	5°	13	HEMT
CBI	30	44'	13	HEMT
MINT	150	30'	4	SIS
VSA	30	7°	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

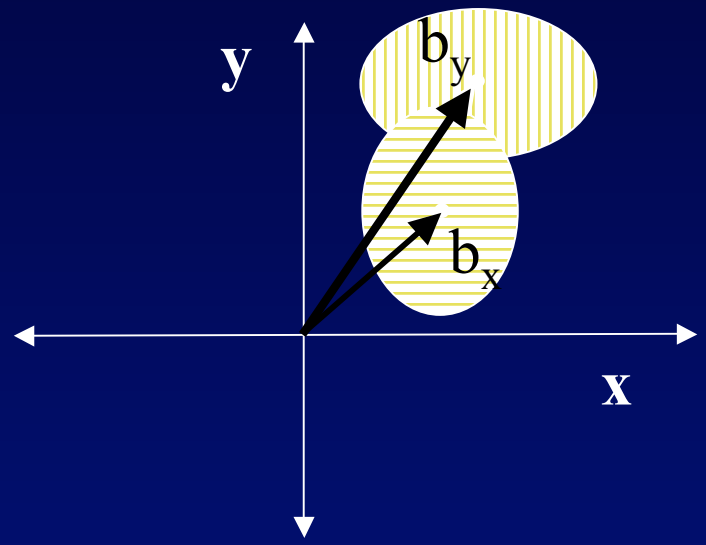
- simple optics - form beams with corrugated horn arrays
  - symmetric beam patterns
  - low sidelobes
  - no polarization or emission from mirrors
- no off-axis aberrations

Why use an interferometer for CMB?(2)

- stability of correlation measurement; Stokes U meas'd directly on single detectors (no differencing of detectors)
- instantaneous differencing of sky signals without scanning
- measures power spectrum directly
- measures both Temp and Polarization anisotropy
- coherent or incoherent receivers/detectors possible
- angular resolution
- alternative to imaging - important to study all options

Polarimeter Systematics: Beam Errors

- beam ellipticity
- relative pointing: $\mathbf{b_x \neq b_y}$
- 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 mismatched beam	OK!

Challenges for Interferometry

- correlate signals from N antennas
- beam combiner - scalable, low loss
- arrays from 30 to 300 GHz
- small *and* large angular scales

Ryle's Adding Interferometer (1952)

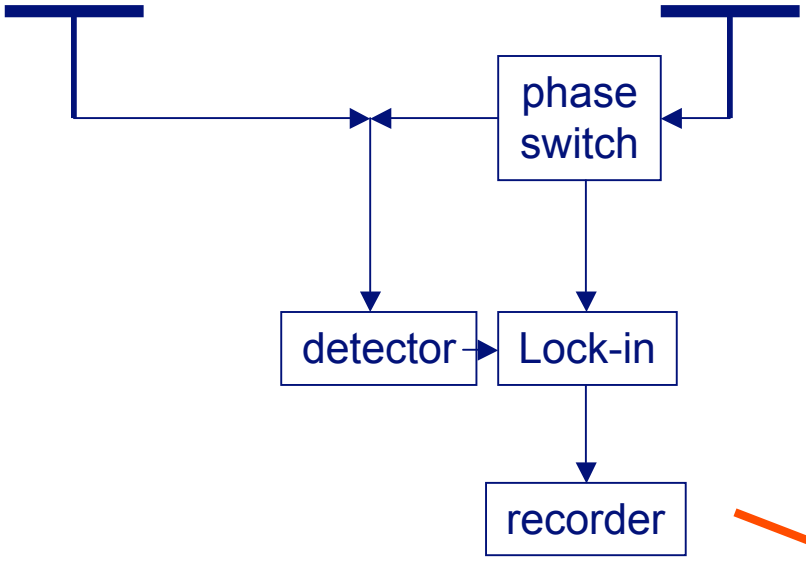


FIGURE 2. Block diagram of the phase-switching system.

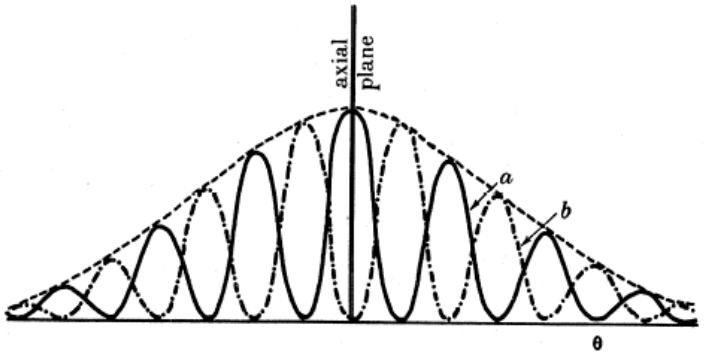


FIGURE 1. Reception pattern of two spaced aerials: (*a*) connected in phase and (*b*) connected in anti-phase.

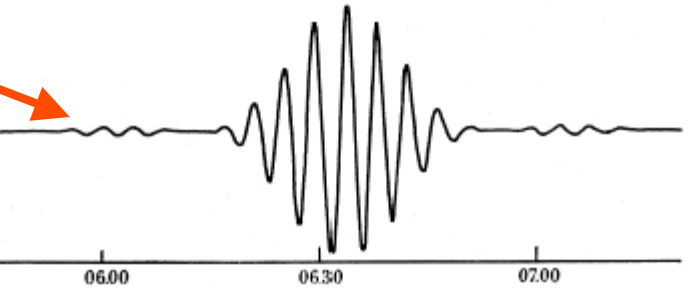
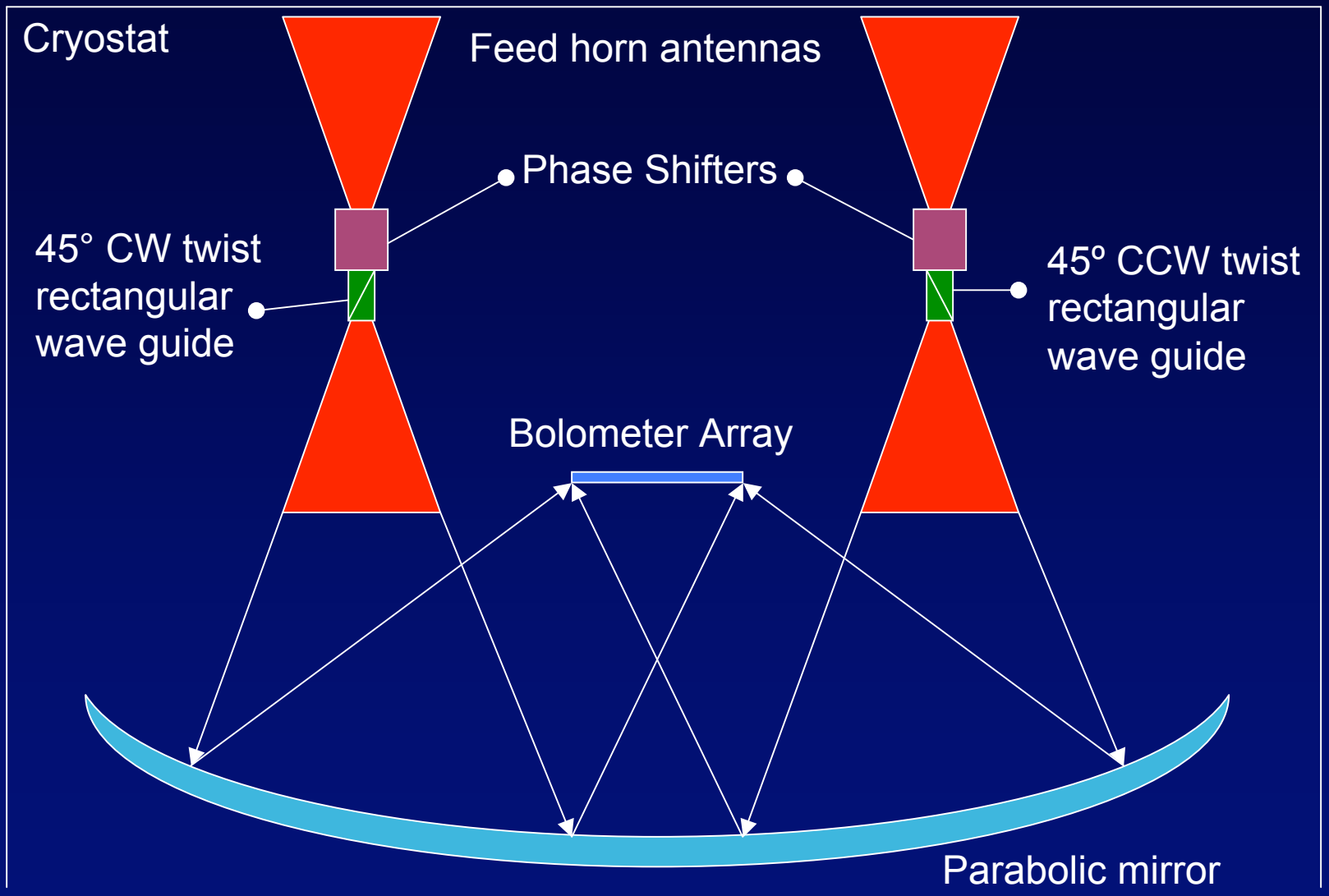


FIGURE 3. Record of the intense radio star in Cassiopeia obtained with the phase-switching system on a wave-length of 3·7 m.

Beam Combination

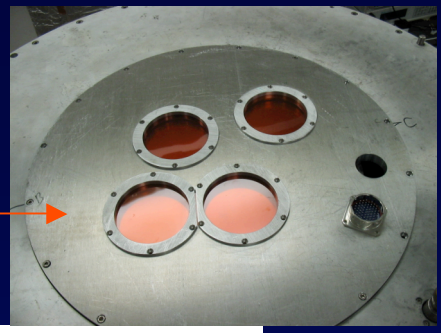
- Michelson: signals are split and combined pairwise
- Fizeau: signals from all antennas appear at all detectors
- Fizeau approach has lower noise in background-limited case, in low *n* limit, Zmuidzinas (2003)
- We studied two Fizeau approaches:
  - guided waves - Butler combiner (w'guide or μstrip)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

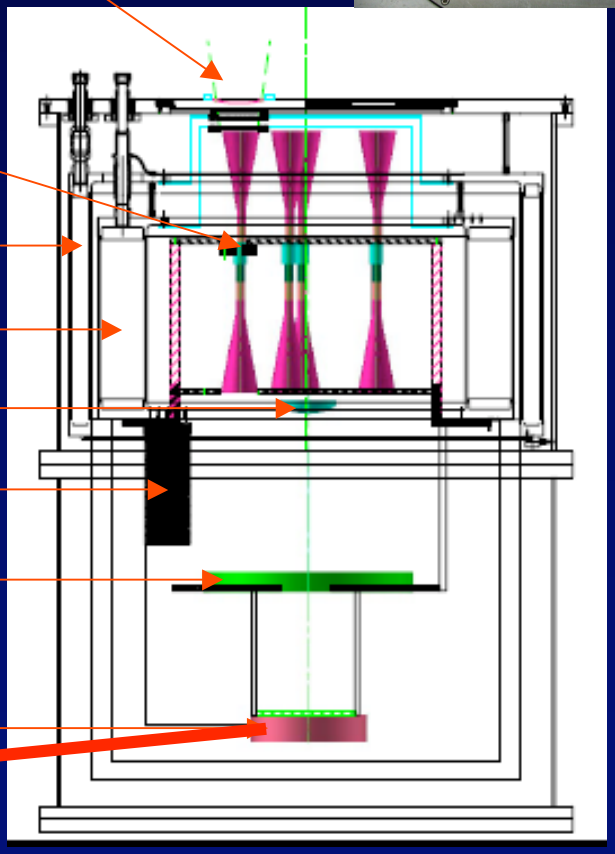
Quasioptical Beam Combiner

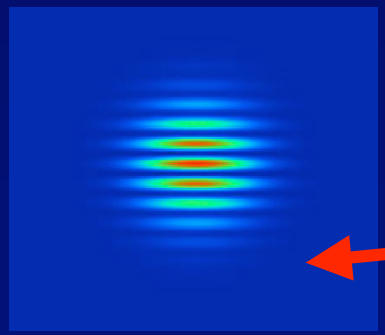


The Millimeter-Wave Bolometric Interferometer (MBI)

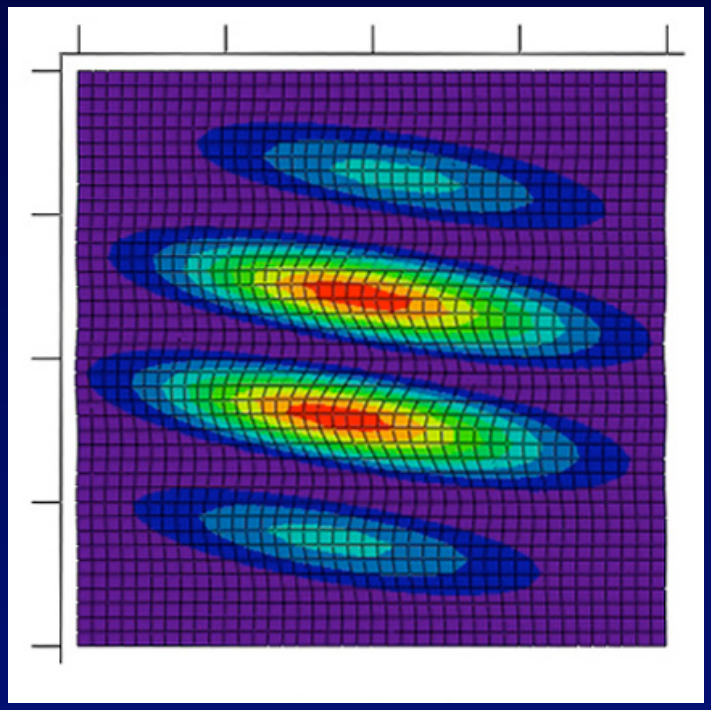
- Fizeau (optical) beam combiner
- 4 feedhorns (6 baselines)
- 90 GHz (3 mm)
- ~1° angular resolution – search for E/B-mode pol'n
- 7° FOV





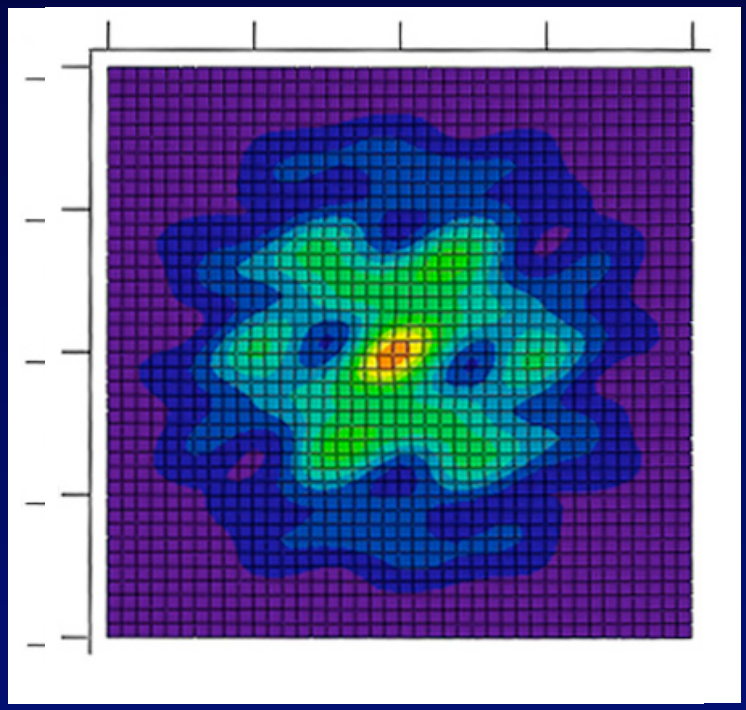


Effect of Phase Shifting



Single Baseline

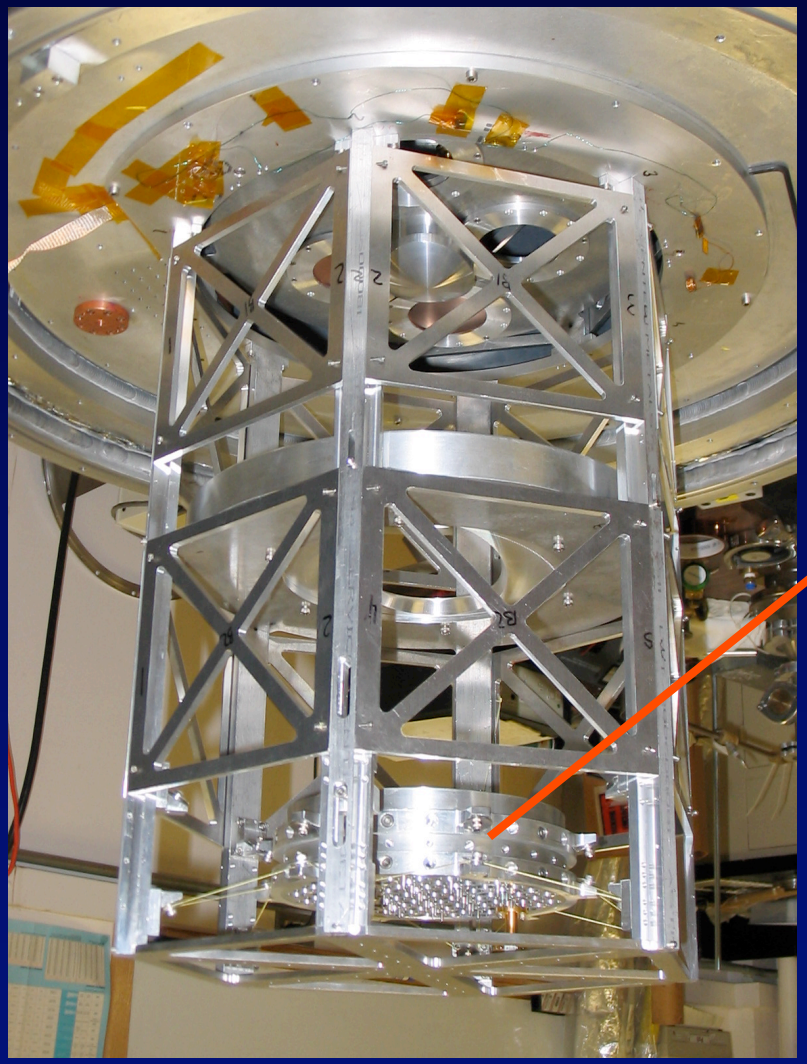
(Two feeds)



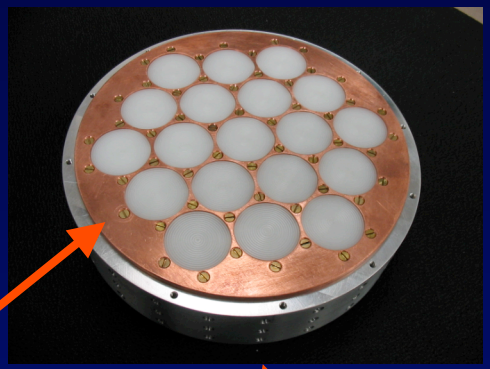
Six baselines

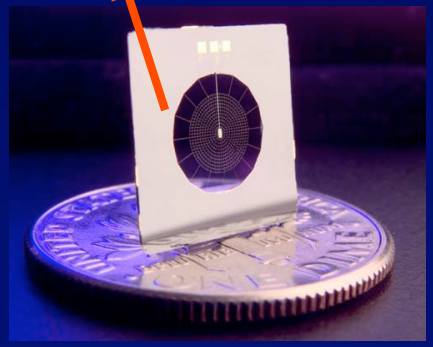
(Four feeds)

MBI Assembly



first light expected 2006
(Madison WI)





19 spider-web bolos (JPL)

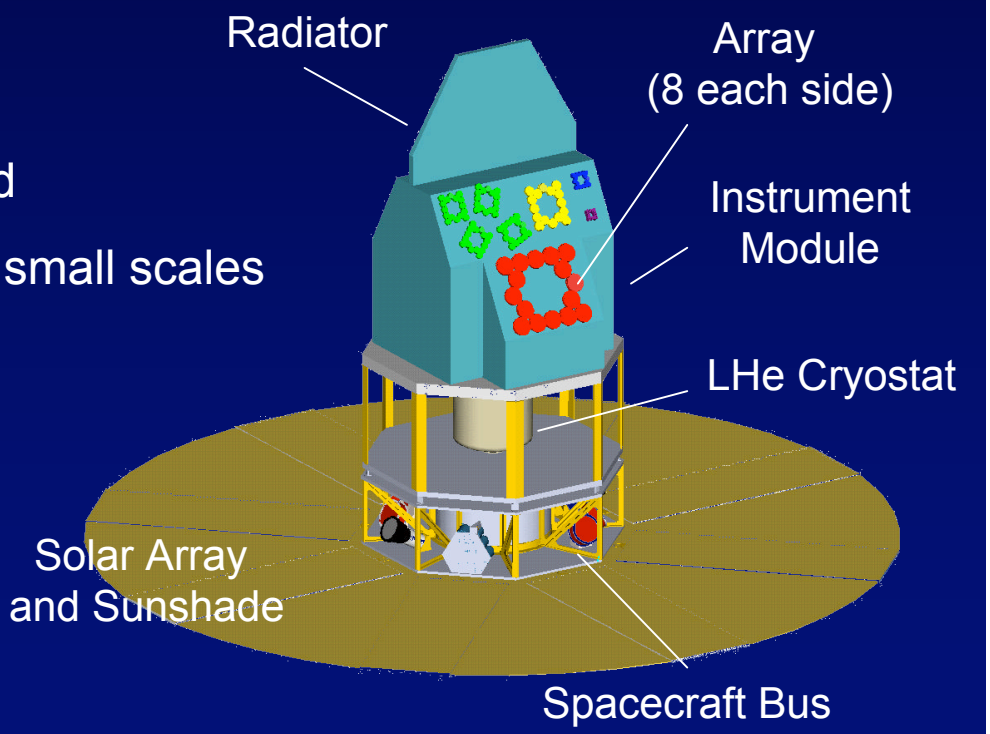
EPIC Mission Concept (1)

- measure CMB *E* and *B* mode polarization over full sky to foreground limit
- close-packed arrays of *N* ~ 16 corrugated horn antennas multiple arrays 30 GHz - 300 GHz
- ~7^{o} FOV, ~ 1^{o} synthesized beam
- total # horns *N* ~ 256 (= # modes)
- interferometer: signals cross-correlated

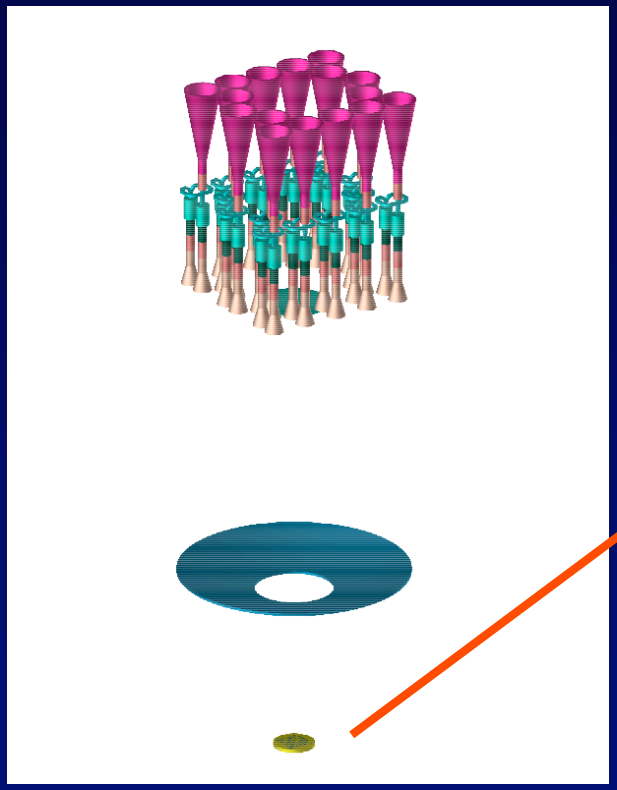
- between horns: *N(N-1)/2* visibilities for small scales

- between 2 polarizations for each horn: "correlation polarimetry" for large scales

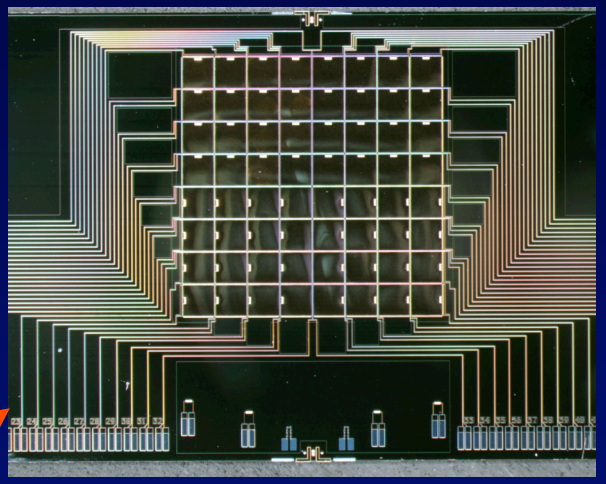
- Delta-II7925H-10
- Lifetime > 1yr from L2



EPIC Mission Concept (2)



16-element module



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

- 4N detectors req'd per array of N horns

Technology Readiness

Technology	TRL	Heritage
Corrugated horn antennas	9 (<100 GHz)	WMAP & COBE
OMT	9 (<100 GHz)	WMAP
Phase modulator	6 (<100 GHz)	BICEP & MBI
Fizeau combiner	5	MBI
Focal Plane Arrays NTD Ge bolometers TES bolometers	 8 6	 Planck & Herschel SCUBA, GBT
LHe Cryostat	9	Spitzer, ISO, Herschel, COBE
Sub-K Cooler: Single-shot ADR	9	ASTRO-E2

EPIC sensitivity (1)

- 256 horns
- 16 arrays of 16 horns
- 30,60,90,150,250 GHz
- 1 year observing
- T/S = 0.01
- comparable to filled-dish measuring *N* modes