CLOVER and BRAIN

New instruments for measuring the B-mode polarization of the CMB

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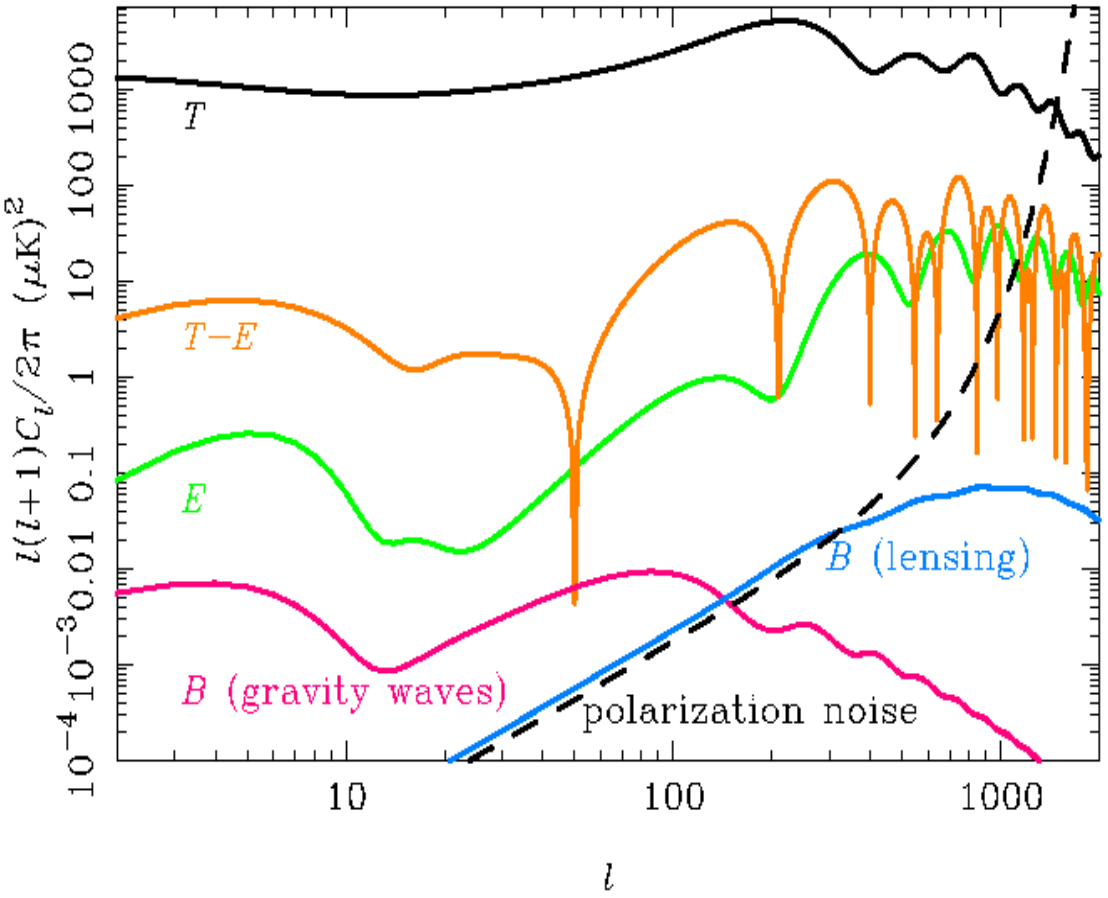
Overview

- Two complementary instrumental techniques
- Will observe on multipoles l=20 -1000

- CLOVER
  - Focal plane array
  - Instrument overview
  - Science forecasts

- BRAIN
  - Bolometric interferometer
  - Instrument aims / overview

Primary science goal



- Primary aim to detect and measure the B-mode polarization power spectrum for l = 20 -1000.
- Sensitivity limited by foreground lensing of the E-mode signal.

Instrument Requirements

- High sensitivity
  - Many detectors
  - Very sensitive detectors (background limited)

- Free of systematics
  - High quality instrument (low side lobes and cross polarization)
  - The ability to subtract systematics

    (leakage from I $\rightarrow$ P)

- Foreground Subtraction (multiple frequency operation)

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Anthony Challinor

Stafford Withington

Ghassan Yassin

Mike Jones

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Keith Grainge

Cardiff University

Walter Gear

Lucio Piccirillo

Peter Ade

Phillip Mauskopf

Bruno Maffei

Giampaolo Pisano

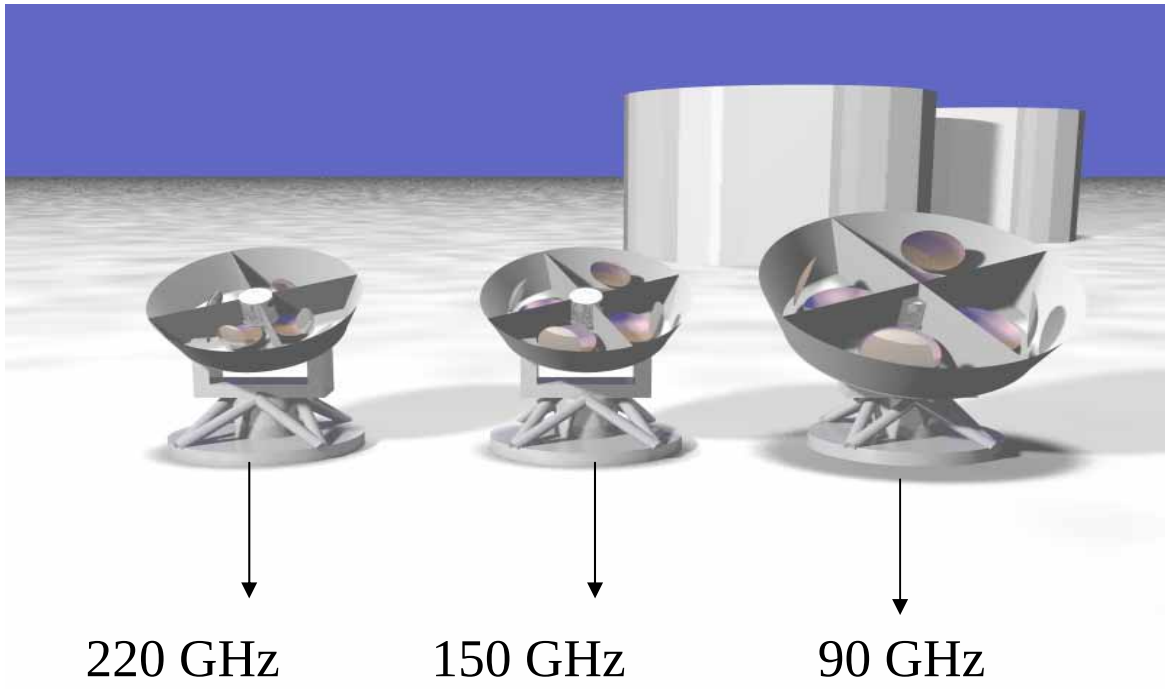
Paris (APC)

Michel Piat
Yannick Giraud-Héraud
James Bartlett
Cyrille Rosset

University of Rome

Paolo de Bernardis

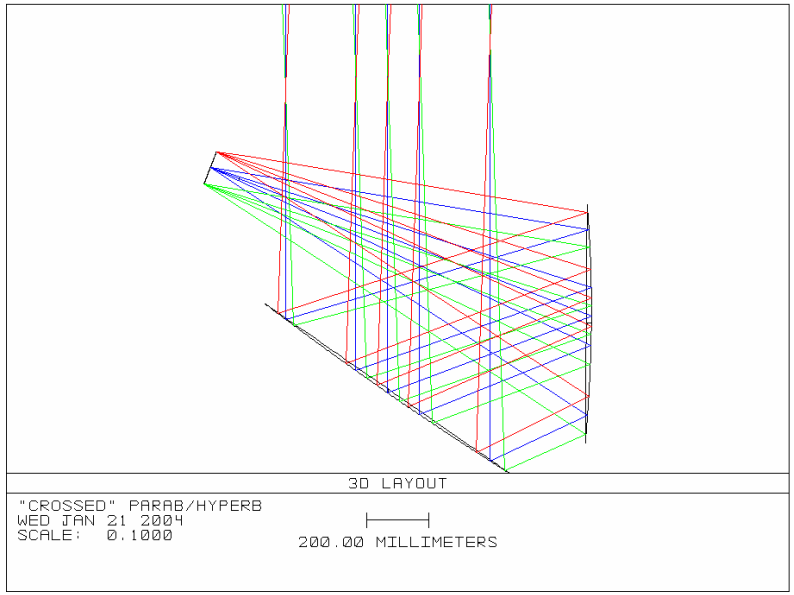
Instrument Layout

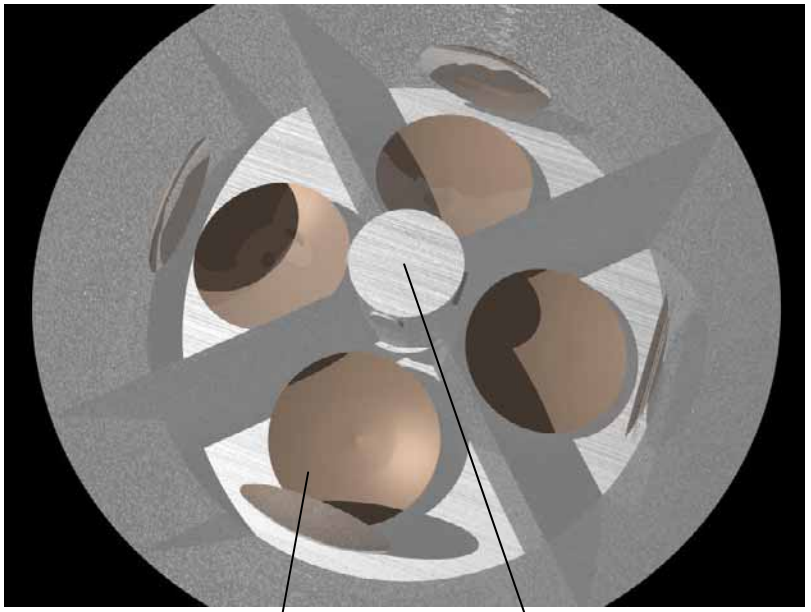


- Three independent telescopes
- Each telescope comprises four co-pointed optical assemblies.
- 15-arcmin resolution with equivalent of 512 single-polarization pixels.
- Phased deployment at Dome-C from 2006-2008

CLOVER

Telescope and Mount





CRA

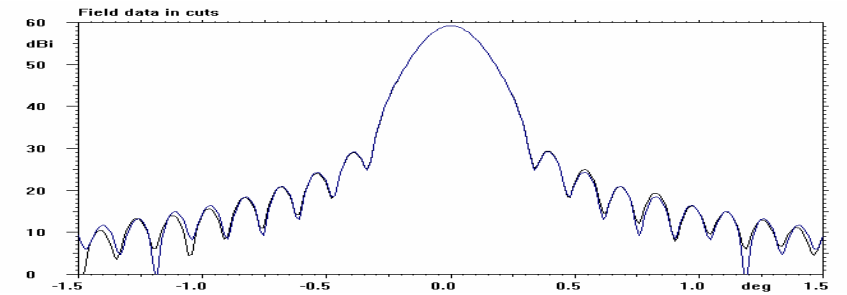
Cryostat with 4 windows

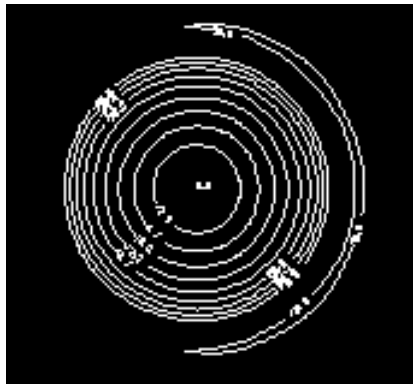
- Compact Range Antenna (CRA)
- Low aberration and cross-polarization
- 4-fold symmetry allows checks on systematics

CLOVER

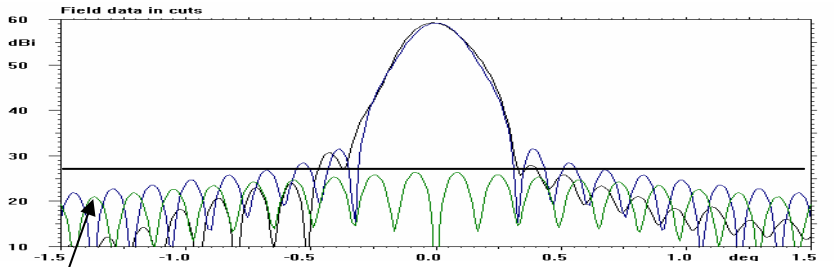
Clover Optics: Radiation Patterns

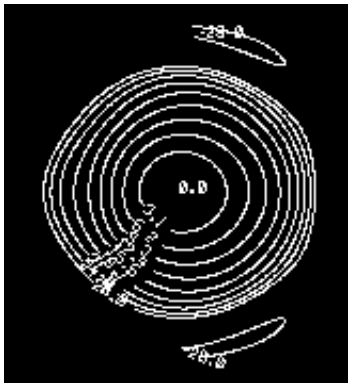
Central Horn





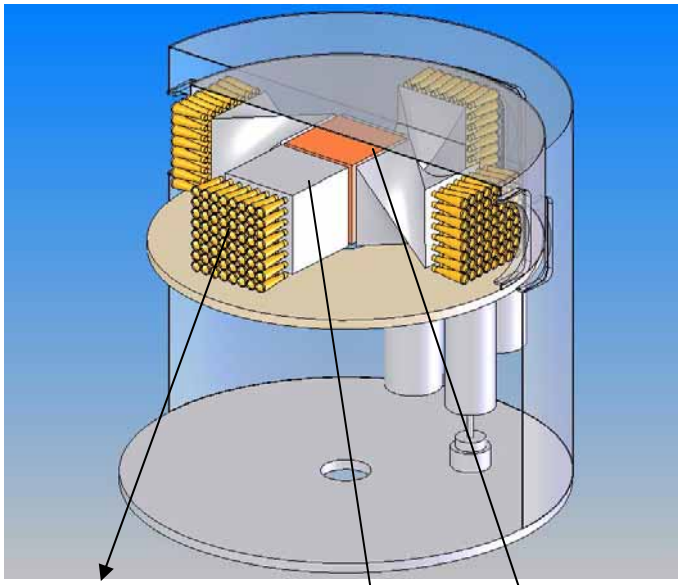
Horn 50mm from centre of array





Worst case cross-polarization - 35 dB

Feedhorn Array

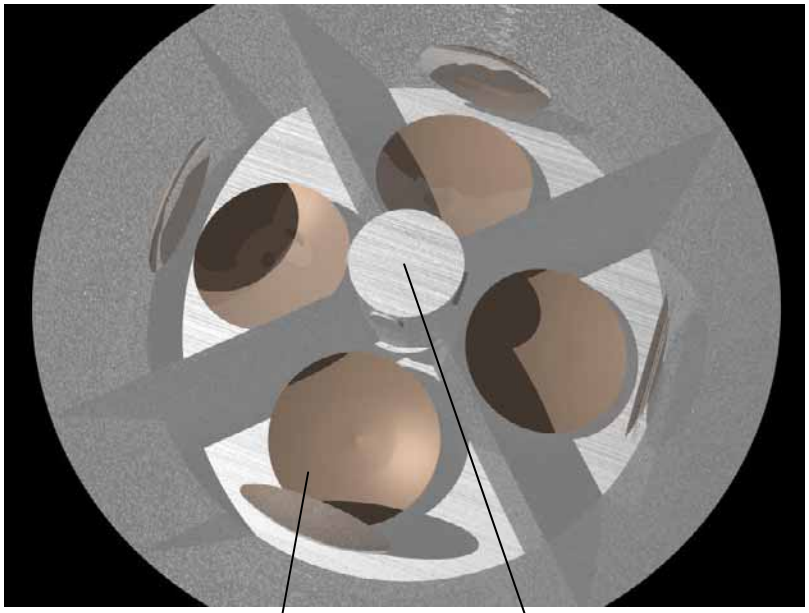


8x8 Corrugated horns array

OMTs

Hybrids

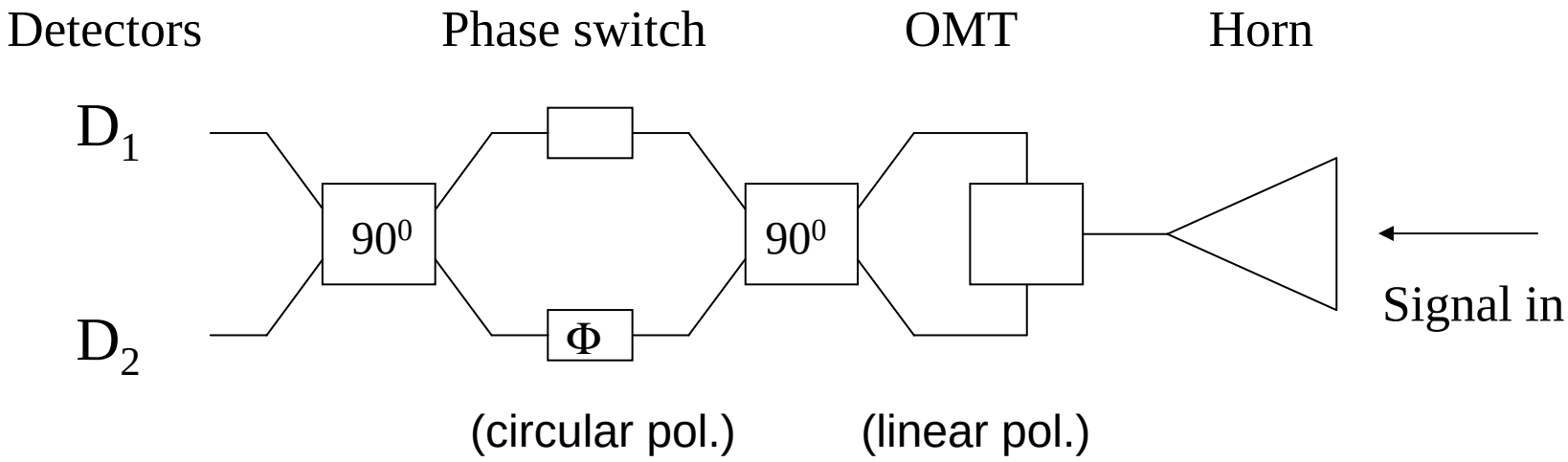
Detector block



CRA

Cryostat with 4 windows

Cross-correlation receiver



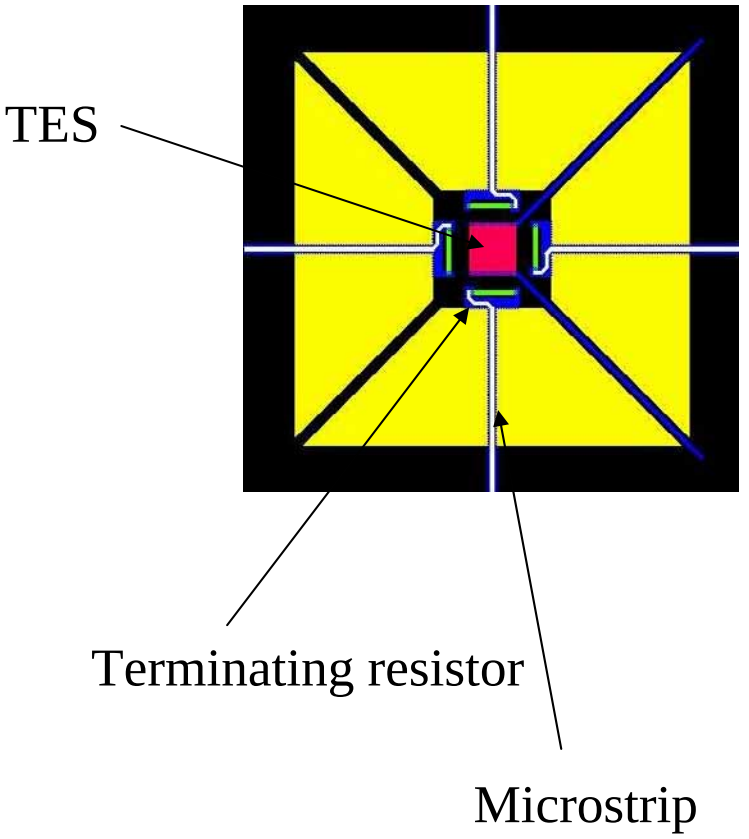
The output at the detectors D_1, D_2

$$D1 = I - Q \cdot \cos\Delta\varphi - U \cdot \sin\Delta\varphi$$

$$D2 = I + Q \cdot \cos\Delta\varphi + U \cdot \sin\Delta\varphi$$

Transition Edge Sensors (TES)

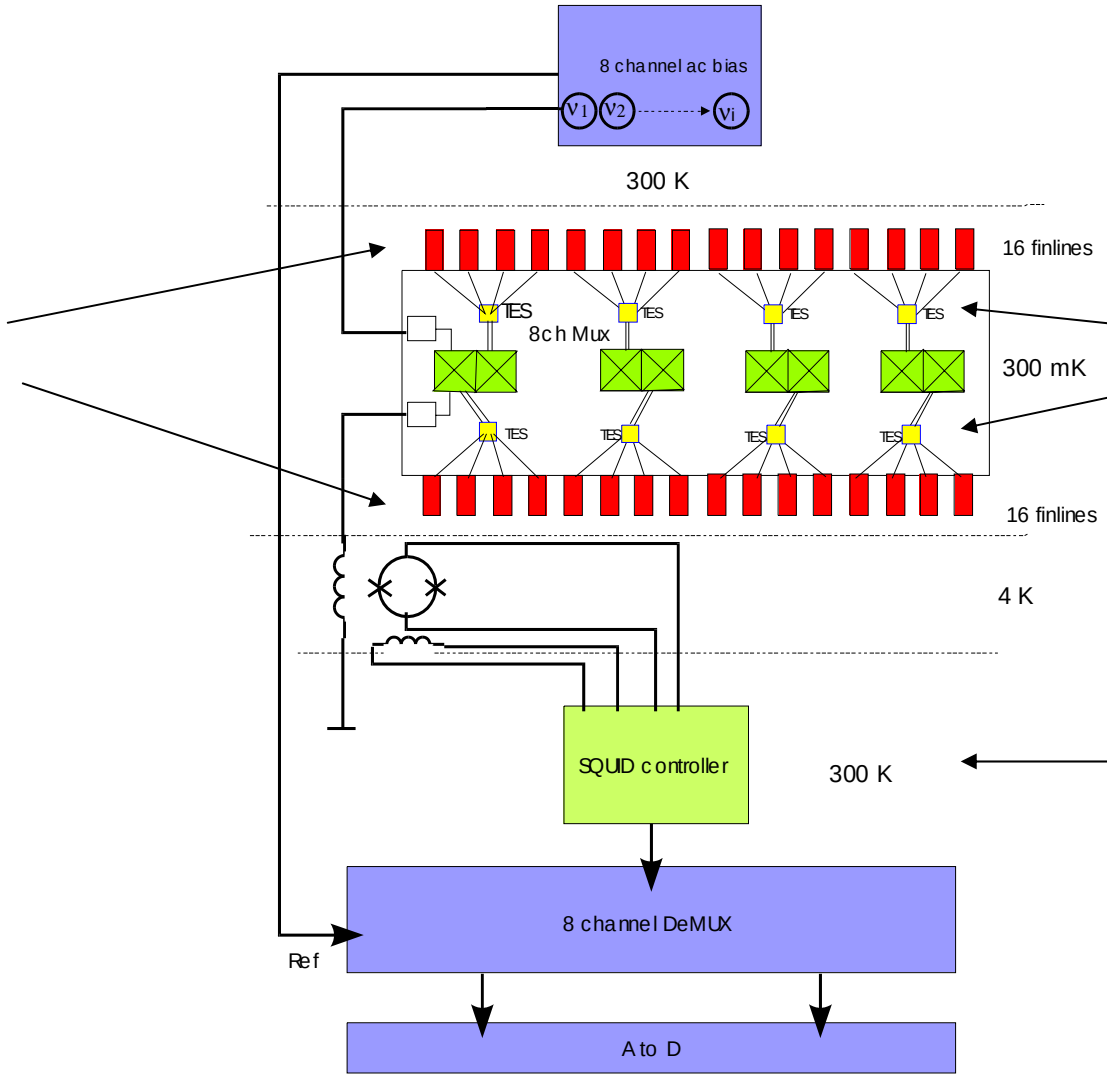
- A 50x50 μm^2 superconducting thin film deposited on a silicon nitrite membrane
- Sharp change in the resistance as the film is heated by absorbing incident photons
- The device is biased at the middle of the transition region between the normal and superconducting states.
- The sharp increase in resistance in resistance causes a decrease in the biasing current which is read by a SQUID



Bolometer Array

INPUT

32 signals from 16 horns



DETECT

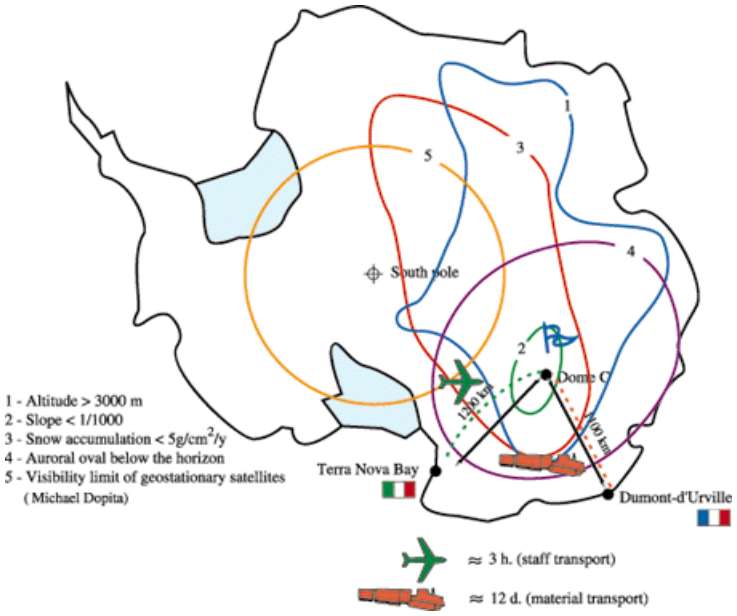
Using 8 TES

READOUT

Multiplex using 1 SQUID

CLOVER

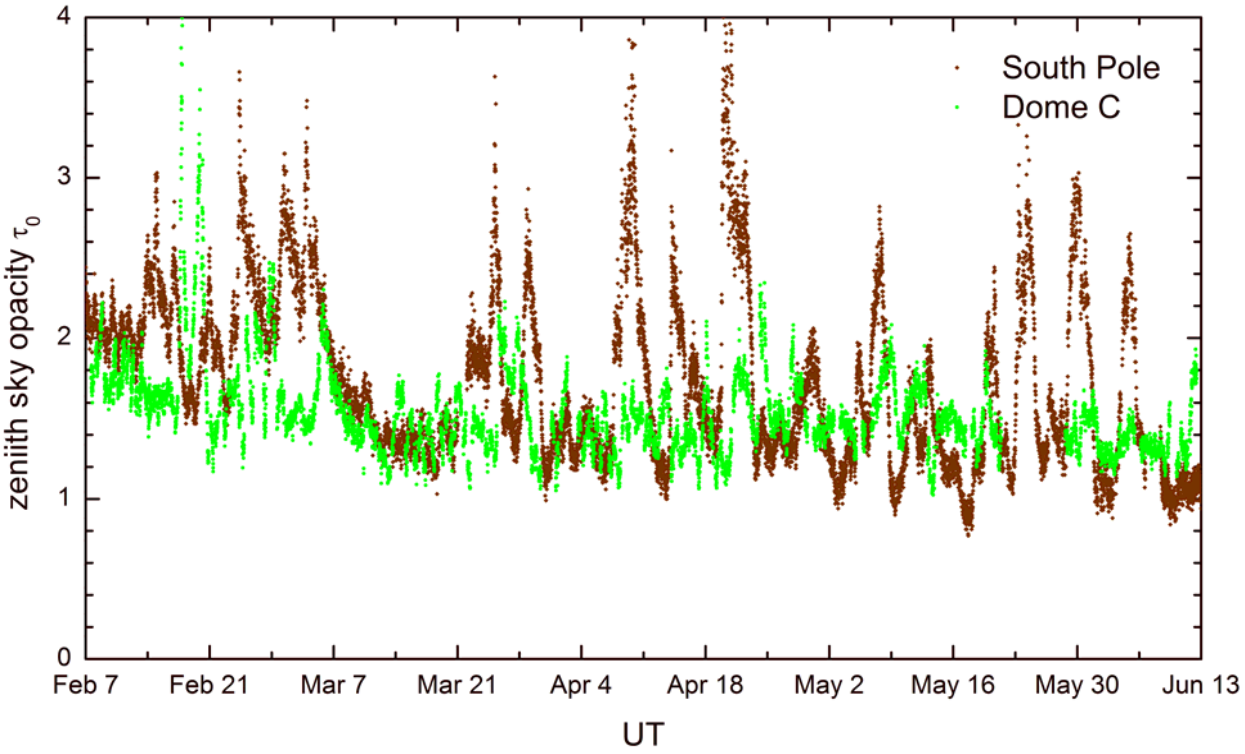
Site: Dome C, Antarctica



- French / Italian base
- 3,200m altitude
- -75 deg latitude
- Slope < 1/1000

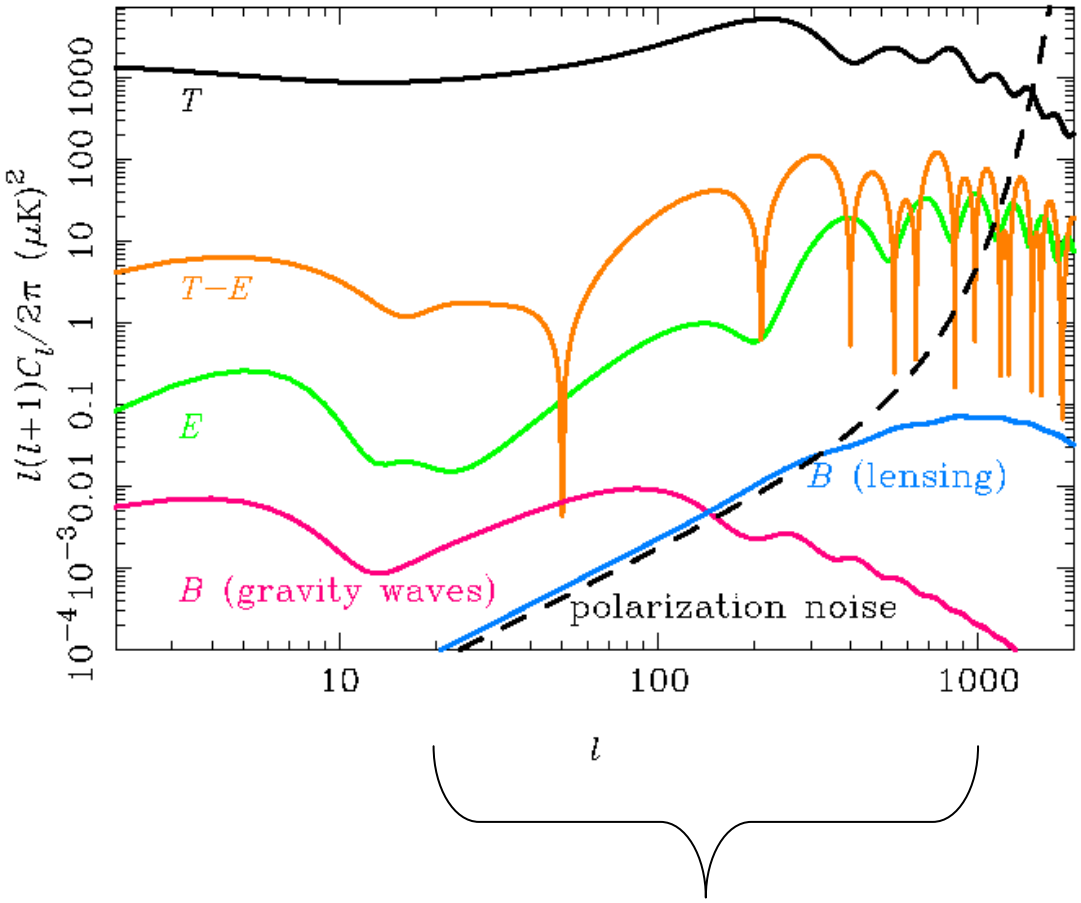
CLOVER

Site: Dome C, Antarctica



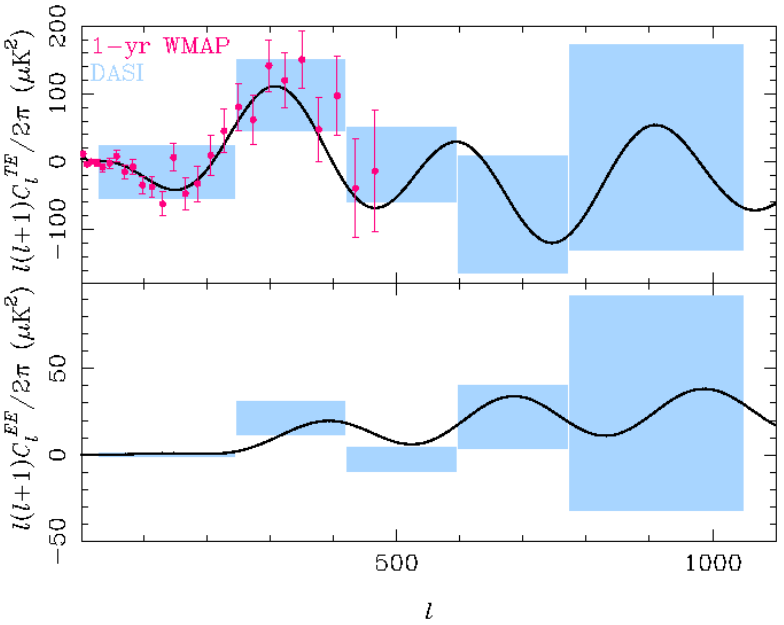
- Comparison of 860GHz opacity
  - South Pole (brown)
  - Dome C (green)

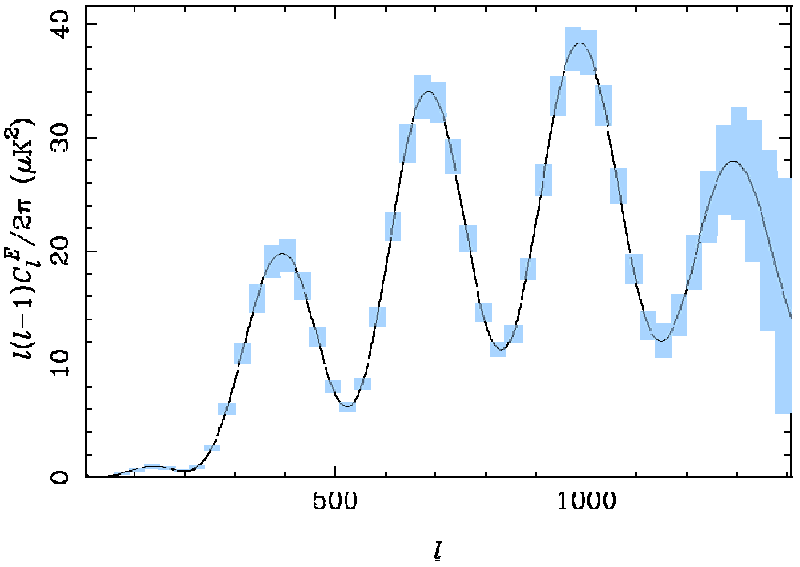
Science Overview



CLOVER : l = 20 - 1000

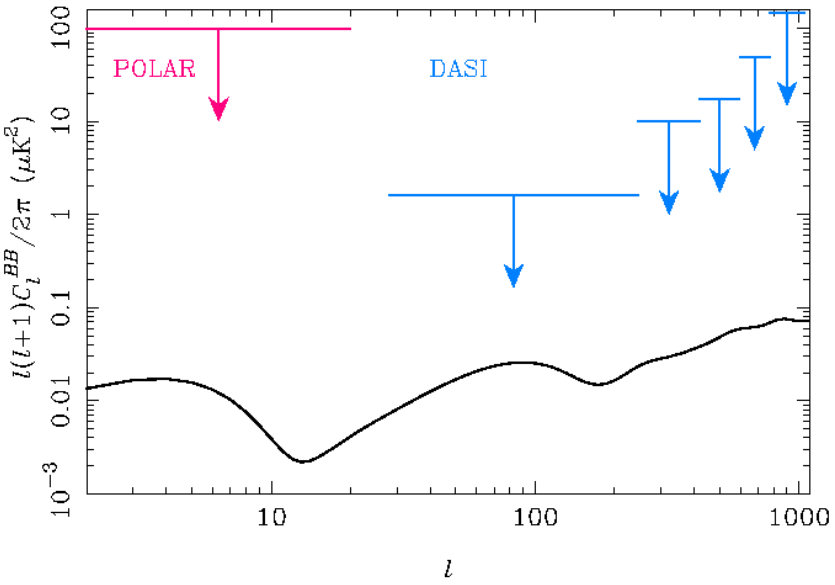
E-mode polarization

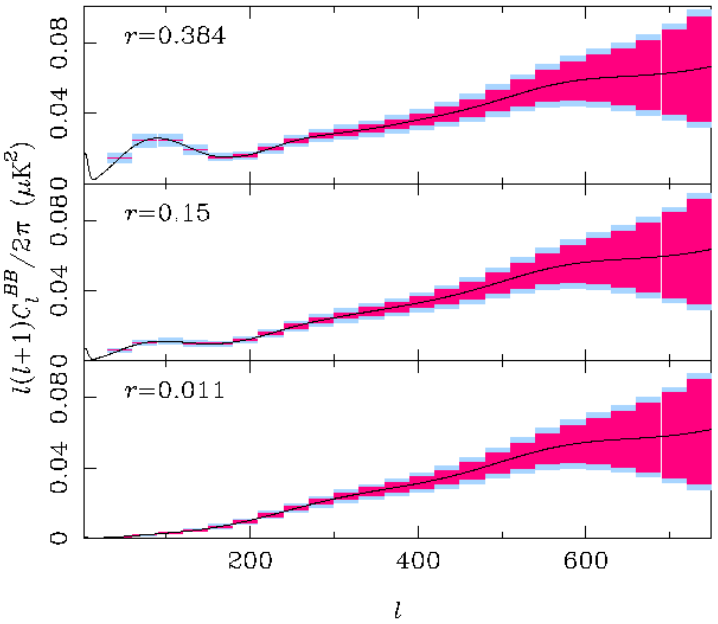




- Assumes 15-deg radius observation with effective sensitivity 200 μK√s after foreground removal and two seasons of integration (~ one year)

B-mode polarization





- Solid line current 68-per cent limit (r = 0.384) from CMB and LSS
- B-mode power spectrum measurement limited by lensing confusion up to l ~ 300 for r < 0.02 (otherwise limited by sample variance of primordial B modes.

Constraining the Energy Scale of Inflation

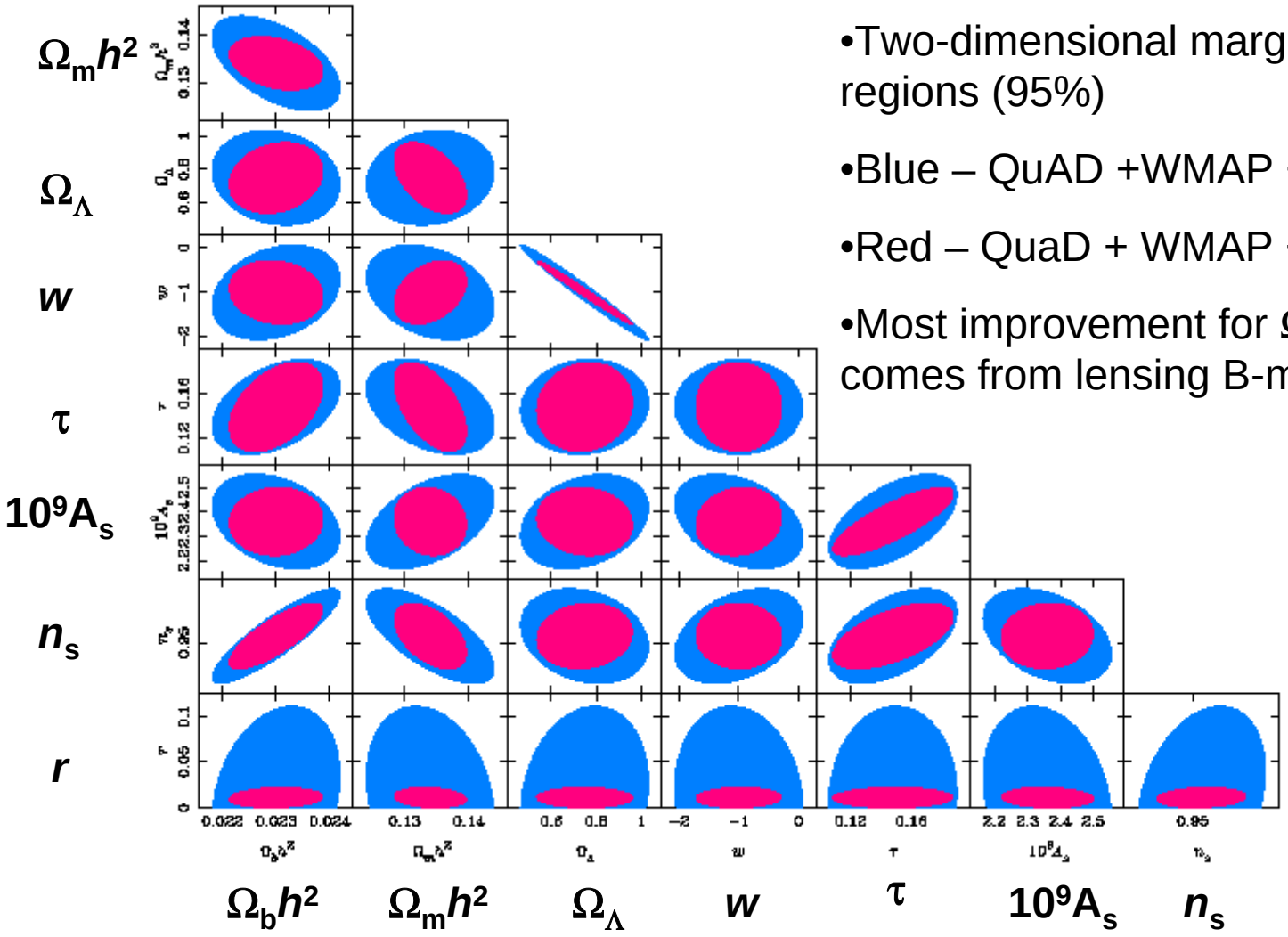
- Tensor amplitude directly related to energy scale of inflation:

$$V^{1/4} = 3.33 \times 10^{16} r^{1/4} (A_s / 2.3 \times 10^{-9})^{1/4} \text{ GeV}$$

- Current upper limit on r (0.384) gives $V^{1/4} < 2.6 \times 10^{16}$ GeV

- 1σ error on r in null hypothesis: $\Delta r = 0.004$
  - Should detect gravity waves from inflation if $V^{1/4} > 0.8 \times 10^{16}$ GeV
  - Dimensionless strain of $\Omega_{GW} h^2 \sim 10^{-16}$ on LISA scales (10^{-4} Hz) c.f. sensitivity of 10^{-13}

Parameter constraints from WMAP + QUaD + BICEP + CLOVER



- Two-dimensional marginalised confidence regions (95%)
- Blue – QuAD +WMAP + BICEP
- Red – QuaD + WMAP +BICEP +CLOVER
- Most improvement for $\Omega_m h^2$,Ω_Λ,w and A_s comes from lensing B-modes.

Clover Timescales

- Funding review this Friday

- If all goes well ...

2006 – 90 GHz

2007 – 90, 150 GHz

2008 – 90,150, 220 GHz

BRAIN

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Angiola Orlando
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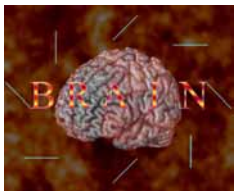


BRAIN Overview

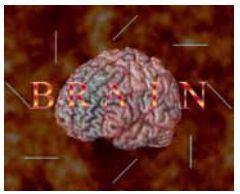
- BRAIN is an interferometry development program

- Will be the first instrument to combine:

    - the superb sensitivity and bandwidth of bolometers
    - the systematic control of interferometers.

- Clover is complementary to BRAIN and uses many similar elements e.g. phase switches & hybrids.

- Ultimate aim to use BRAIN to measure the B-mode signal at low-l where sensitivity and systematic control paramount.

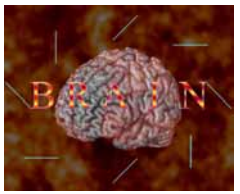


Technology Development

- The final instrument will require:
  - 256 horns
  - ~30,000 baseline combinations

- Low-loss, wide-band phase switches
- Beam combining
- Ultra-low loss signal path
- Fast, sensitive detectors

Single baseline is now funded and being built

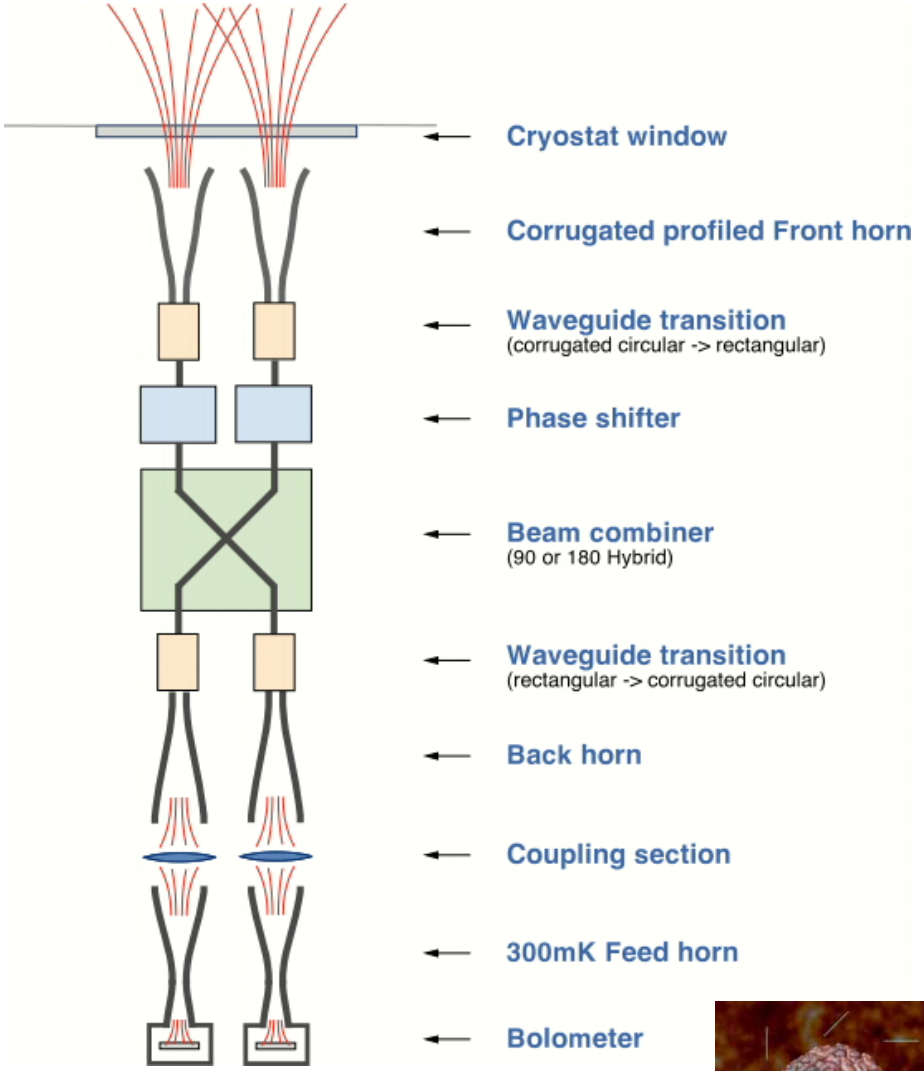


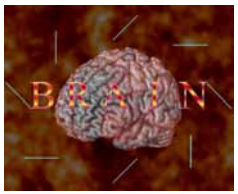
Current plans

- Make single baseline out of available bits.
  (Archeops horns, Planck readout…)
- Operate at 90 GHz
- Take to Dome C in 2005.

If all goes well...

- Develop large-format combination arrays.
- 256 horns, ~30000 baselines, 3 frequencies
- A B-mode instrument for low-l within the next 5 years.





Summary

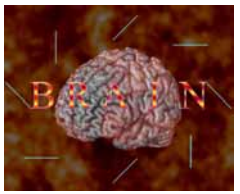
Have described 2 complementary experiments to measure B-mode polarization within the next 5 years.

CLOVER

- focal plane array utilising pseudo-correlation techniques
- will measure l = 20 – 1000
- aim to be limited only by foreground signals
- phased deployment to Dome C 2006 – 2009.

BRAIN

- the first bolometric interferometer
- test the required technology by 2004/5
- aim for complete instrument within 5 years.

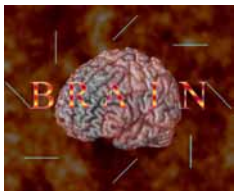


Bolometric Interferometery

- Can use bolometric detectors as multiplying element:

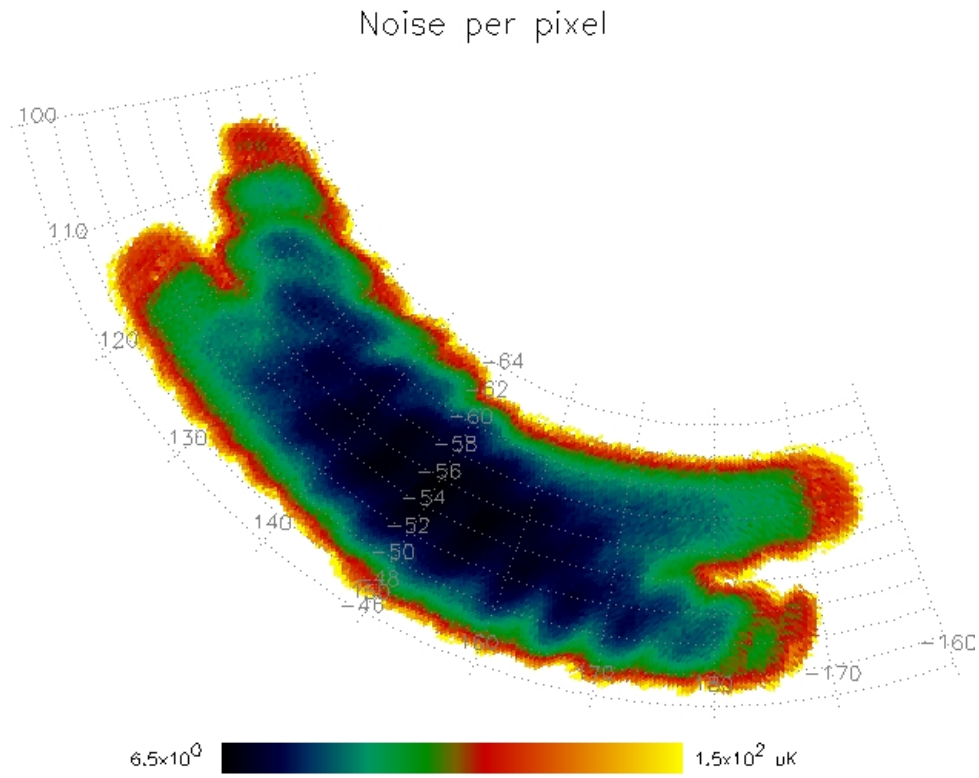
$$(A + B)^2 = A^2 + B^2 + 2AB$$

- Potential is to combine:
  - bandwidth & sensitivity of bolometers
  - systematic properties of interferometers.

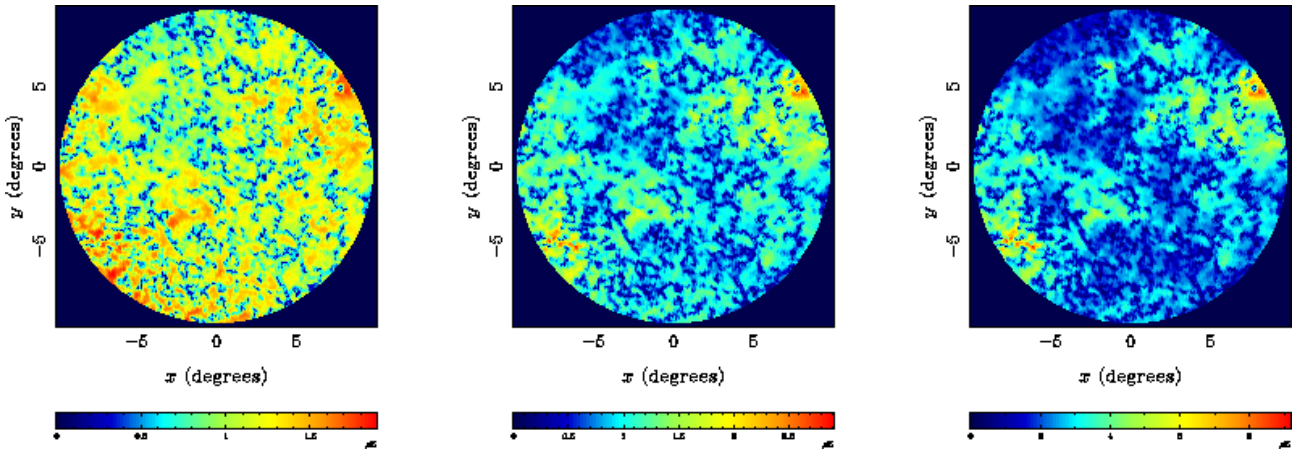


Scanning Strategy

- Multi-cross strategy
- Scan in azimuth, elevation constant
- Return to same sky patch so cross-link
- Periodically rotate telescope about pointing axis
- Ideally want circular patch, 15-deg radius



Foreground Removal

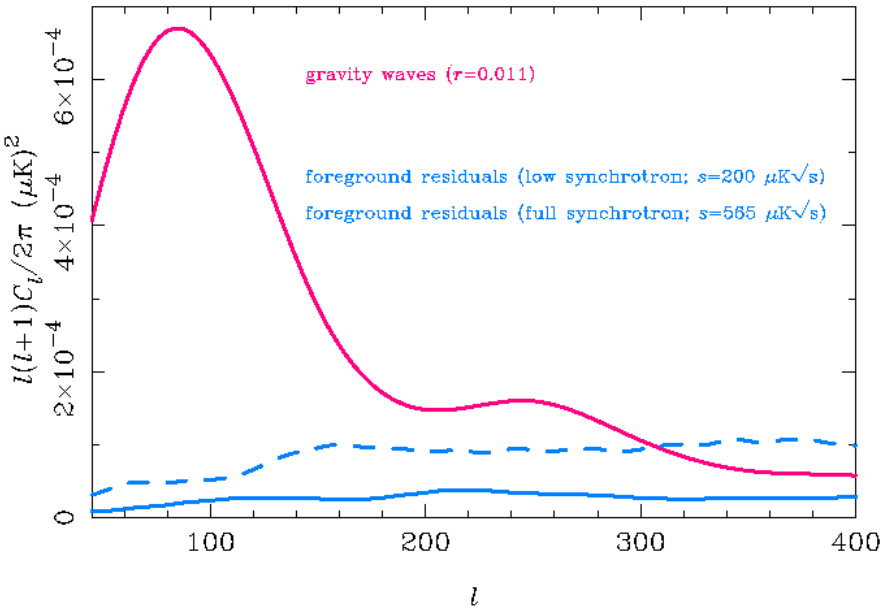


•Synchrotron based on maps of Giardino et al. (2002) extrapolated with their spectral index map for total intensity

•Dust based on Finkbeiner, Davis & Schlegel (1999), assuming 10-per cent polarization fraction aligned with synchrotron (worst case).

CℓOVER

Foreground Removal



• Simple linear combination technique assumes no spectral or spatial information for foregrounds.

CℓOVER