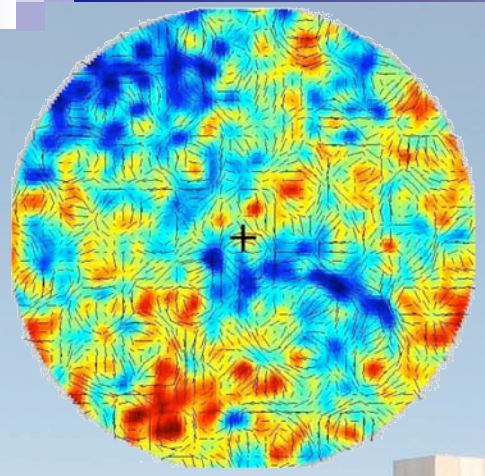
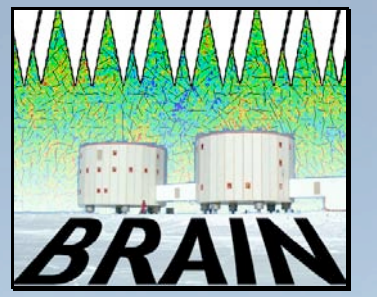


Precise measurement of CMB polarisation from Dome-C: the BRAIN experiment



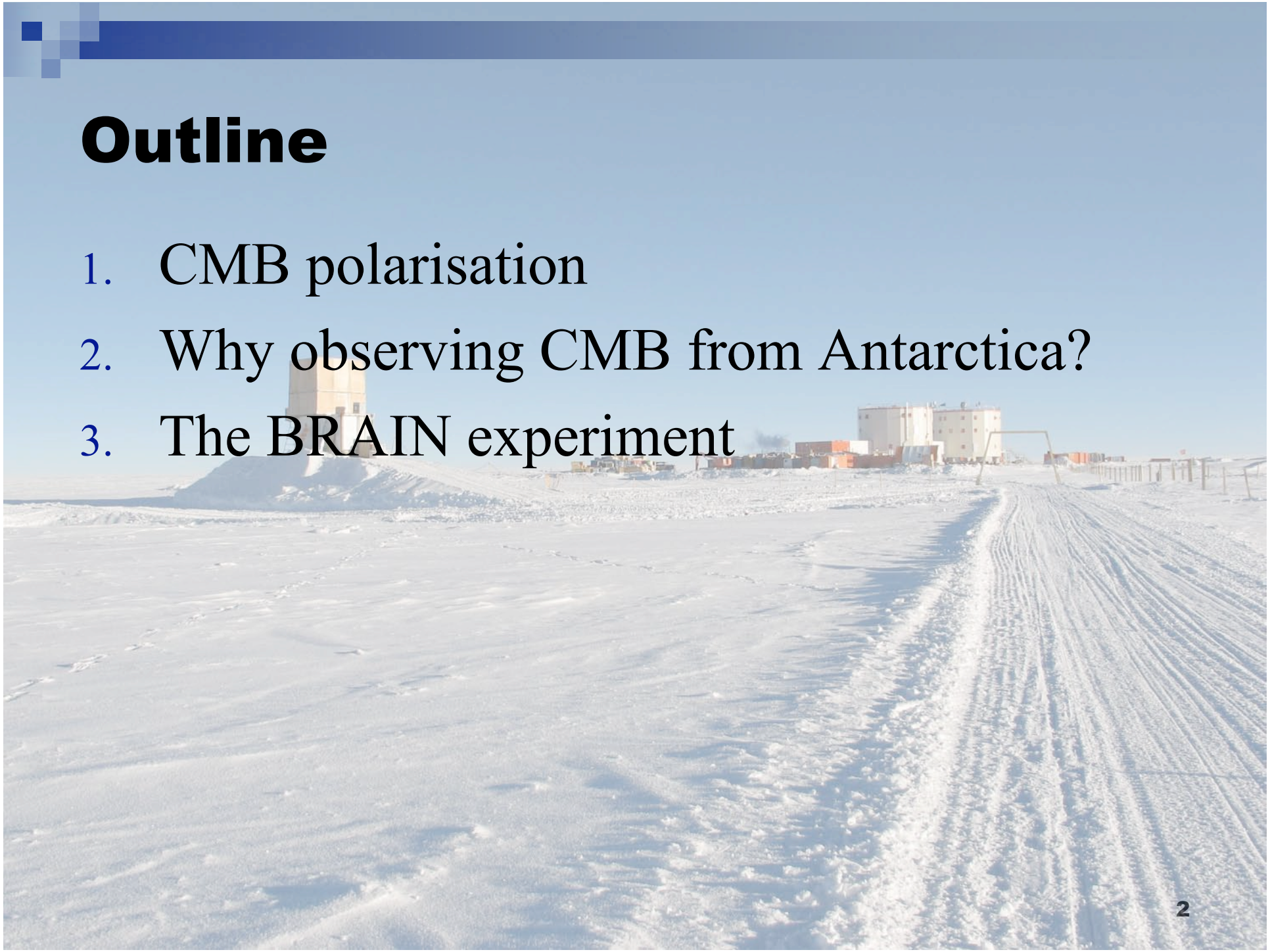
Michel Piat for the BRAIN collaboration

Laboratoire Astroparticule et Cosmologie

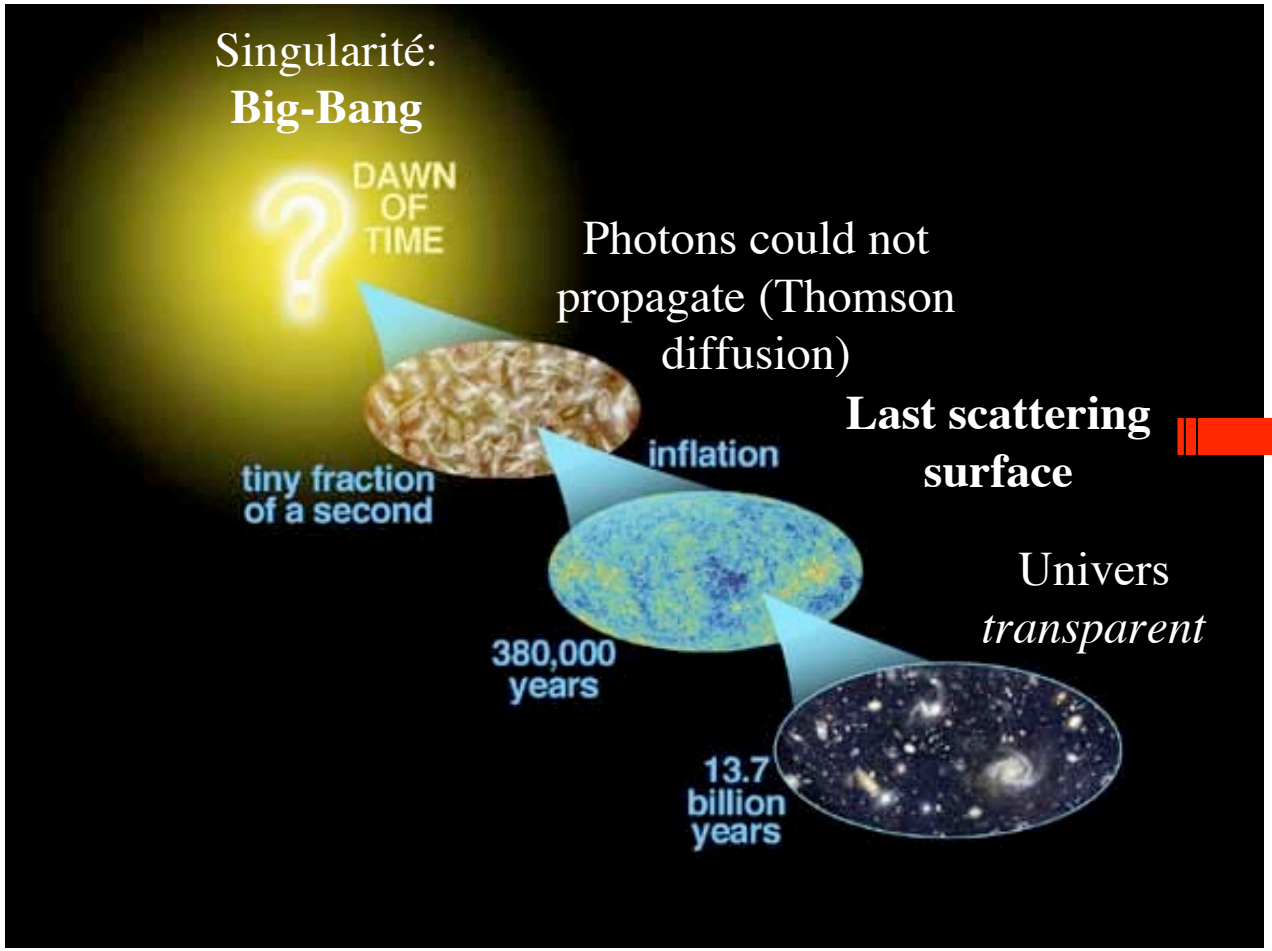
Université Paris 7 Denis Diderot

Outline

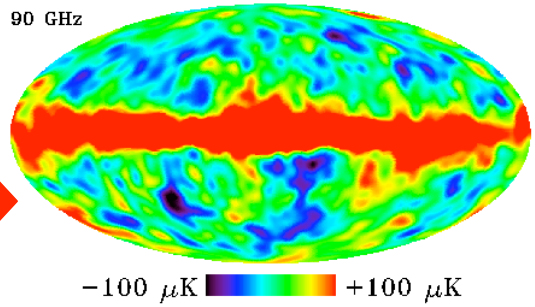
1. CMB polarisation
2. Why observing CMB from Antarctica?
3. The BRAIN experiment



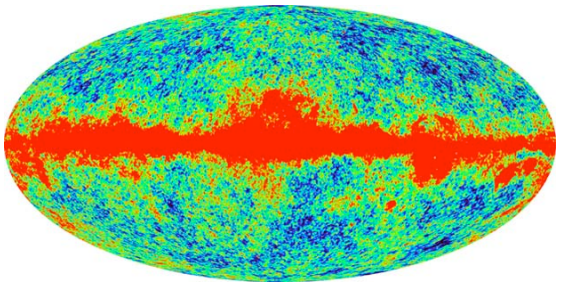
1. The Cosmic Microwave Background



COBE (1989)
T=(2.728±0.004)K
$\Delta T/T \approx 10^{-5}$ à 7°

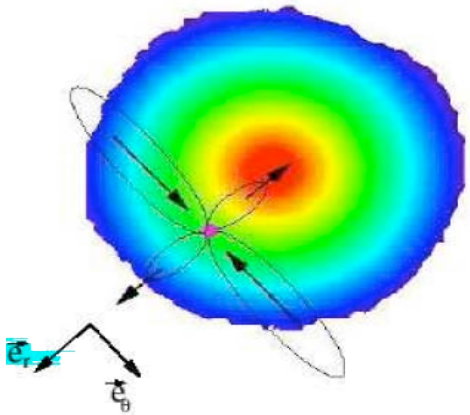


WMAP (2002)

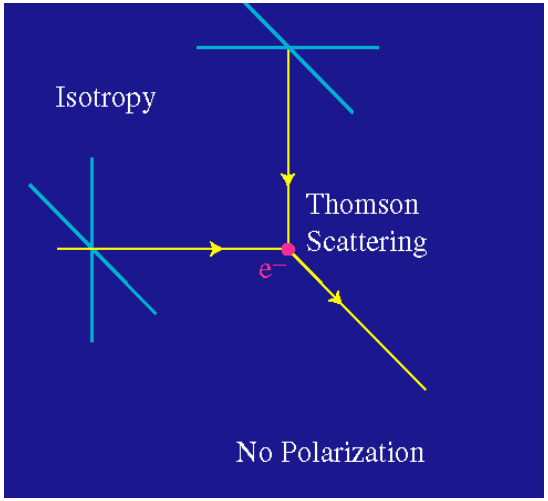


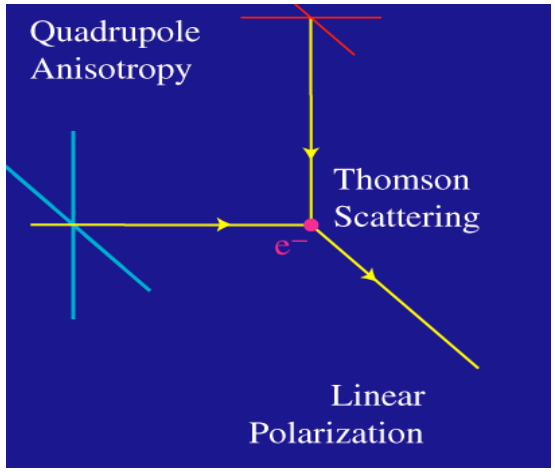
Polarisation of the CMB

- Thomson scattering at decoupling
- Requires an anisotropic incident radiation to the electron
  - **Electron falling in an overdensity:**

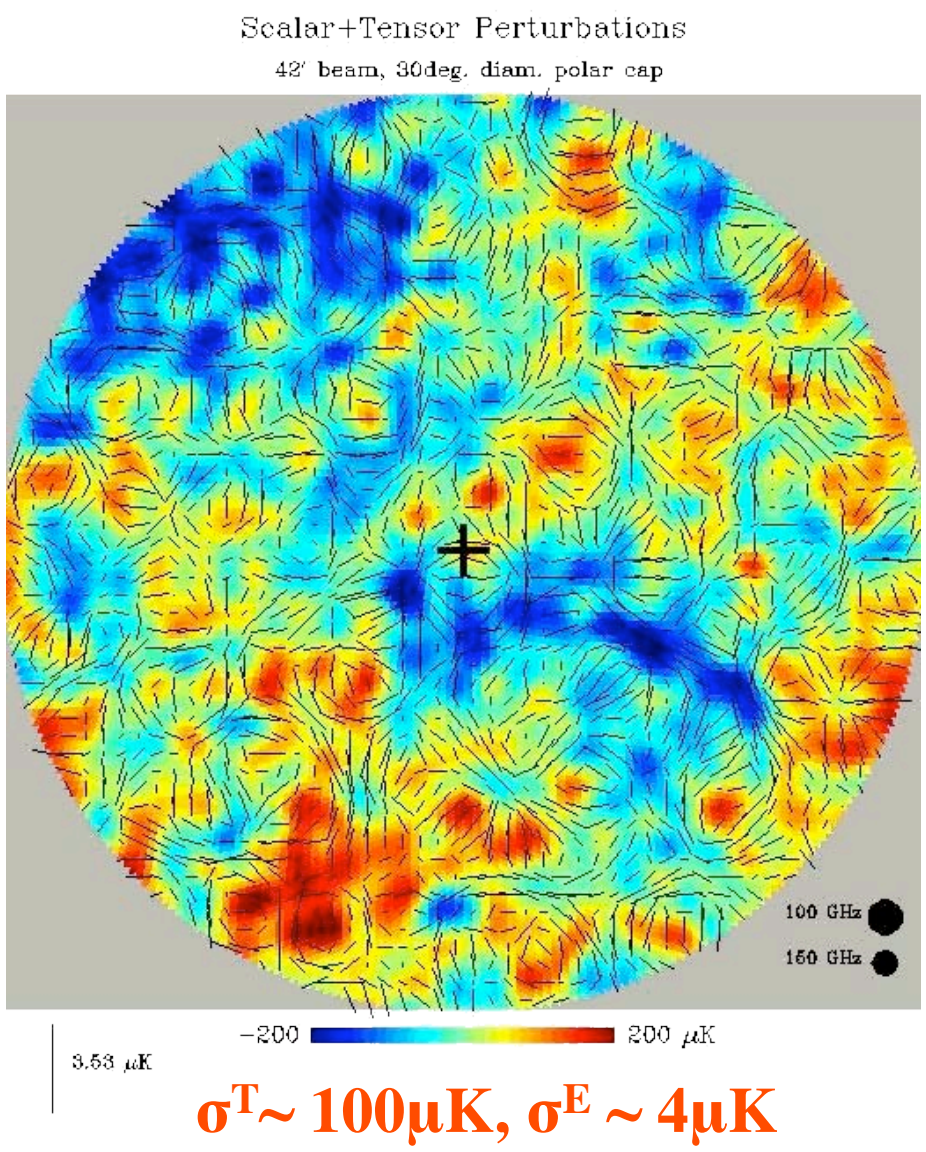


- Linear polarisation of about 10%

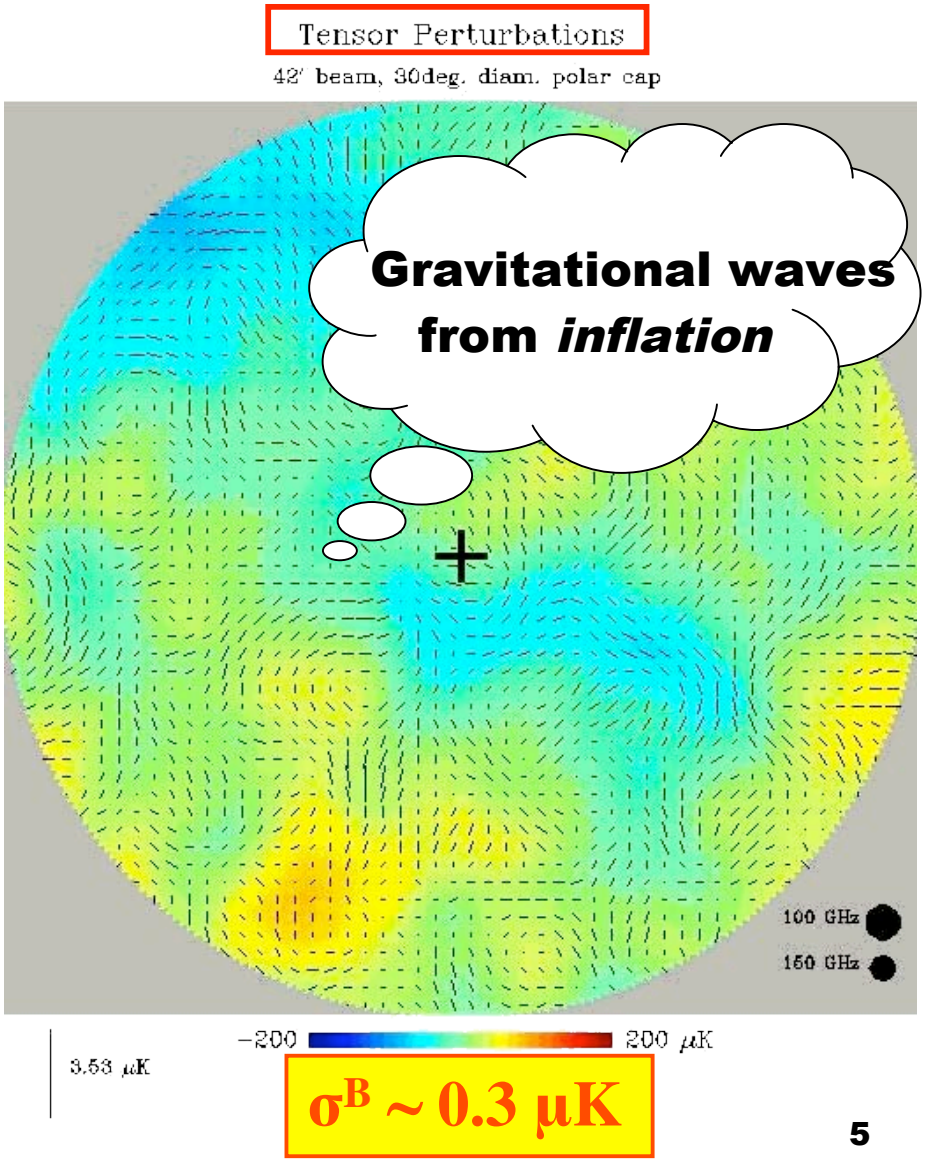




Polarised signal (simulations)



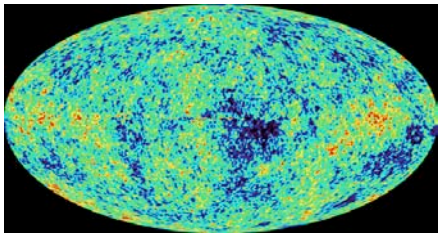
$\sigma^T \sim 100\mu K$, $\sigma^E \sim 4\mu K$



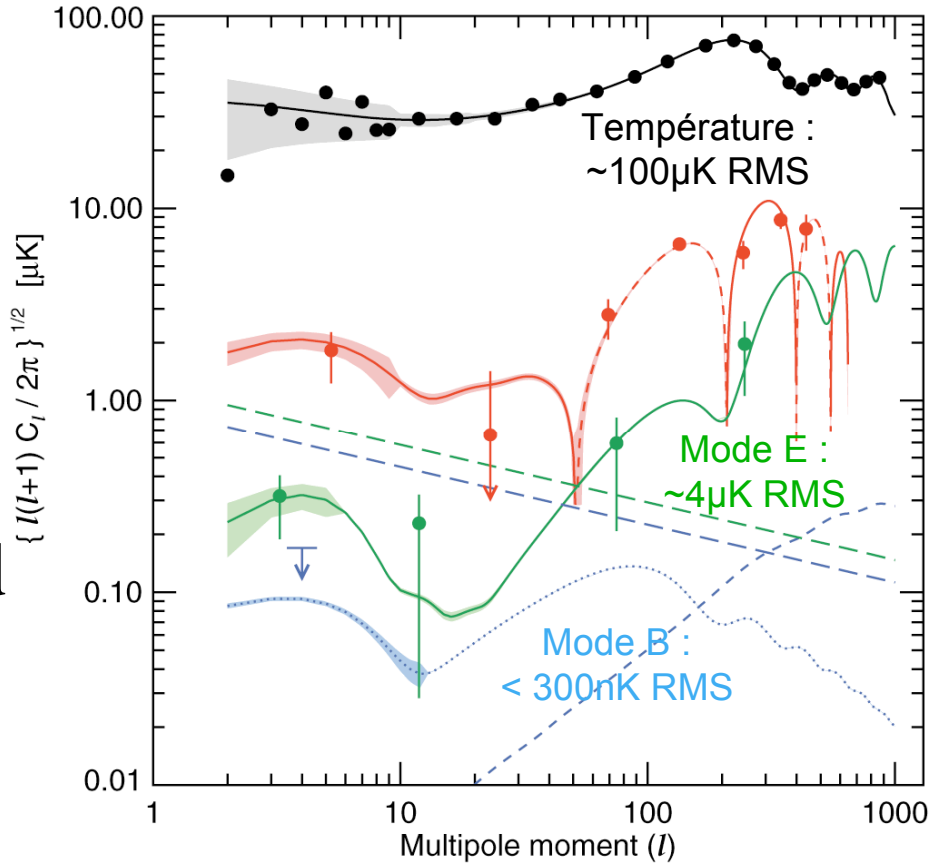
$\sigma^B \sim 0.3\ \mu K$

www.astro.caltech.edu/~lgg/bicep_front.htm

CMB power spectra

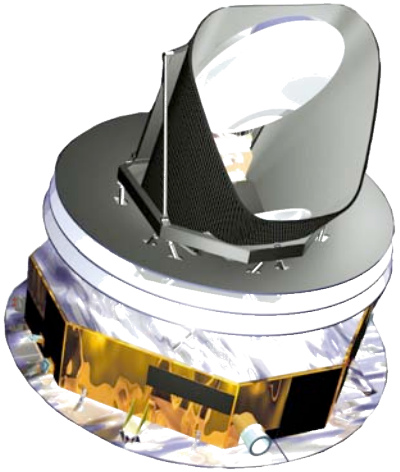


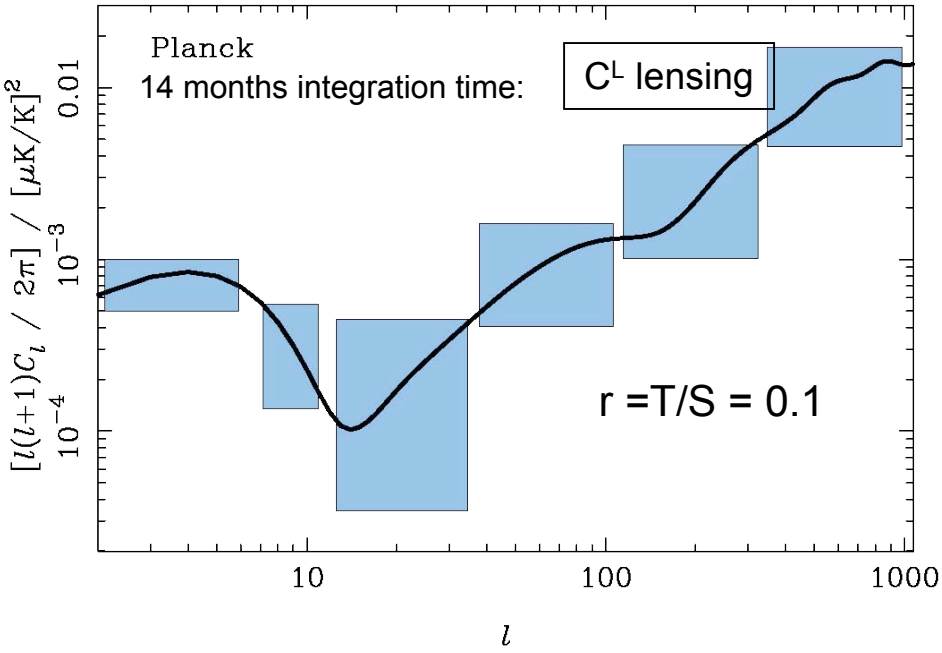
- Polarised signal: very weak…
  - **Fluctuations < 10^{-6}**
- E Mode detected
  - **DASI, WMAP, Boomerang…**
- B Mode not yet detected
  - **Depends on r=T/S**
  - **r < 0.28 at 95% CL (WMAP+SDSS, Spergel et al. 2006)**



Planck satellite and B-modes

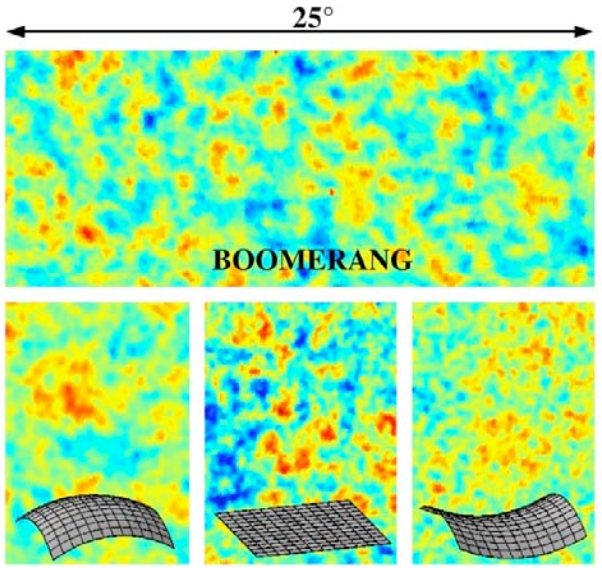
- Planck (2008)
  - **Designed to be limited by confusion limit from unpolarised astrophysical foregrounds**
  - **“Ultimate experiment” for T anisotropies**
- Planck polarisation sensitivity
  - **Limited by instrumental noise**
- **Marginal measurement of B-modes…**





2. Why observing the CMB from Antarctica?

- A lot of CMB experiments in Antarctica:
  - **Python (1992-1997)**
  - **VIPER (1997-2000)**
  - **Boomerang (Balloon, Pol, 1998, 2003)**
  - **ACBAR (Pol, 2000-03?)**
  - **DASI (Pol)**
  - **BICEP (Pol)**
  - **QUAD (Pol)**
  - **(not exhaustive list)**

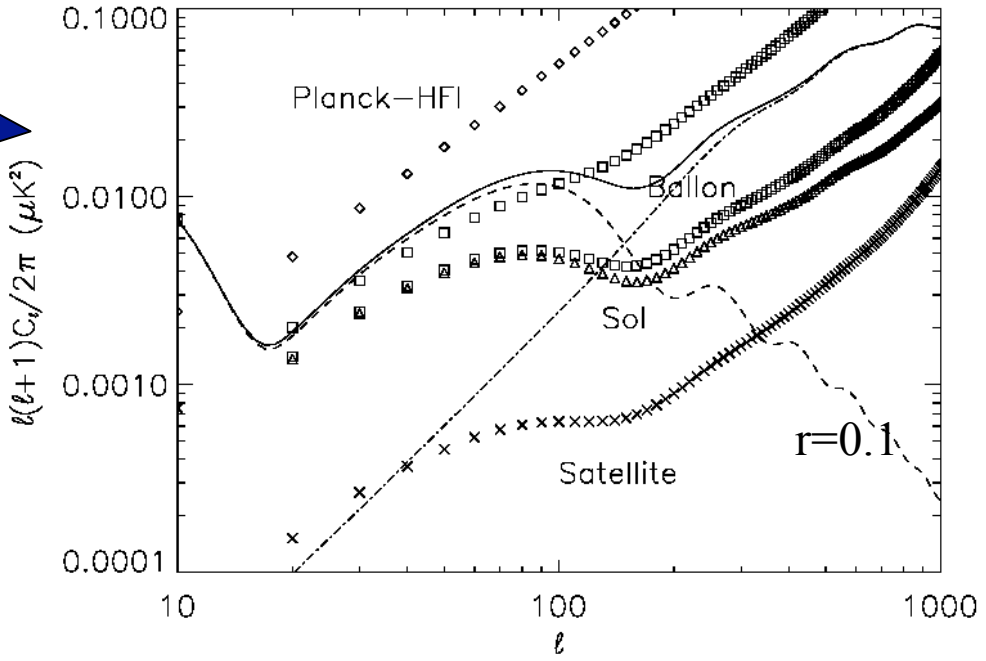


Strategy to look for B-modes

- possible experiments:

Experiment type	f_{sky}	Integration time	Detector sensitivity	N_{Bolos}
Ground based (Antarctique)	0,01	6 months	300µKs^0.5	1000
Balloon	0,01	1 day / 10 days	100µKs^0.5	1000
Satellite	1	1 year	100µKs^0.5	1000 (4)

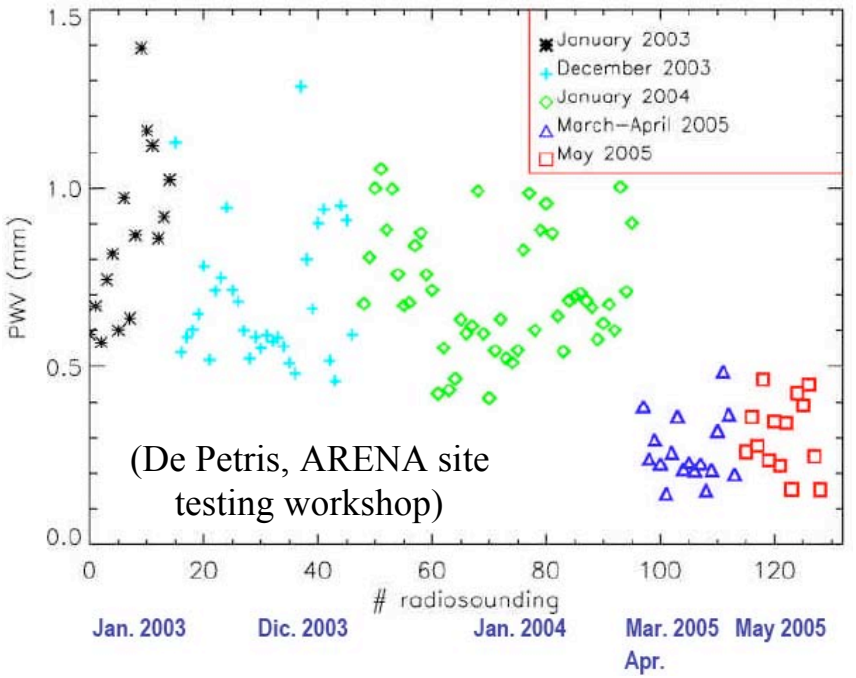
- Measurement errors on B modes:
- **Ground based and satellite experiments**
- Requirements for a ground based experiment:
  - **Large number of detectors**
  - **Long integration time**
  - **Small patch on the sky**



(DEA training period B. Quenez, 2003)

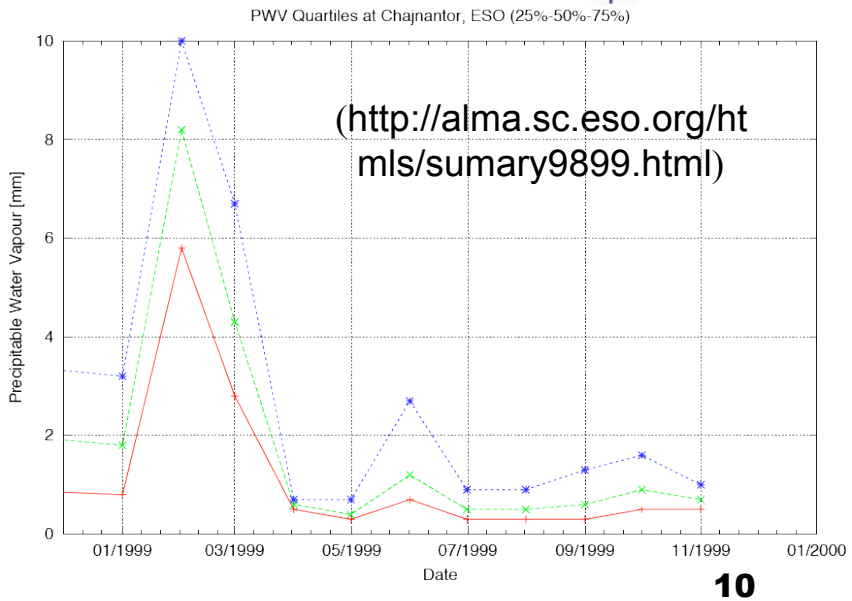
The atmosphere in the mm: PWV

- Dome-C
  - **PWV < 500μm always in the winter**



(De Petris, ARENA site testing workshop)

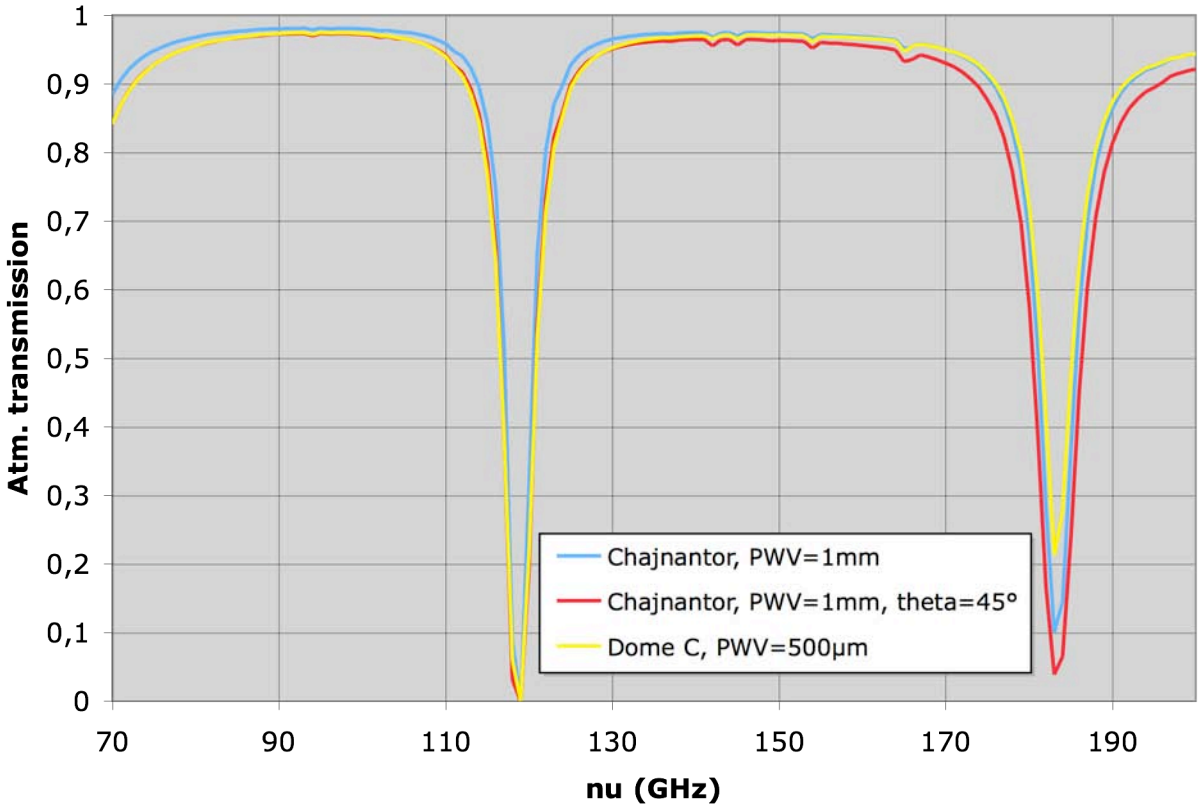
- Chajnantor
  - **PWV < 1mm for about 50% of time in the winter**



(http://alma.sc.eso.org/htmls/sumary9899.html)

Transmission of atmosphere in the mm

- Comparison Dome-C / Chajnantor site (Chile, ALMA site)

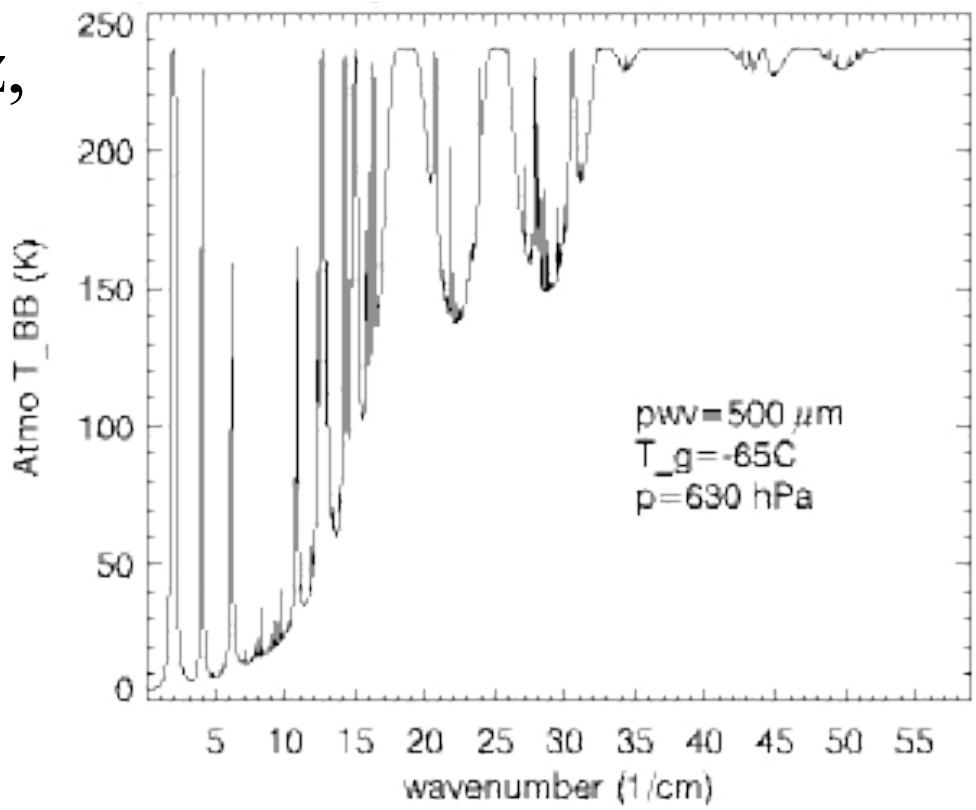


No big differences… but lets have a deeper analysis…

Equivalent brightness temperature of the atmosphere

- Assuming ν=150GHz, 30% bandwidth:

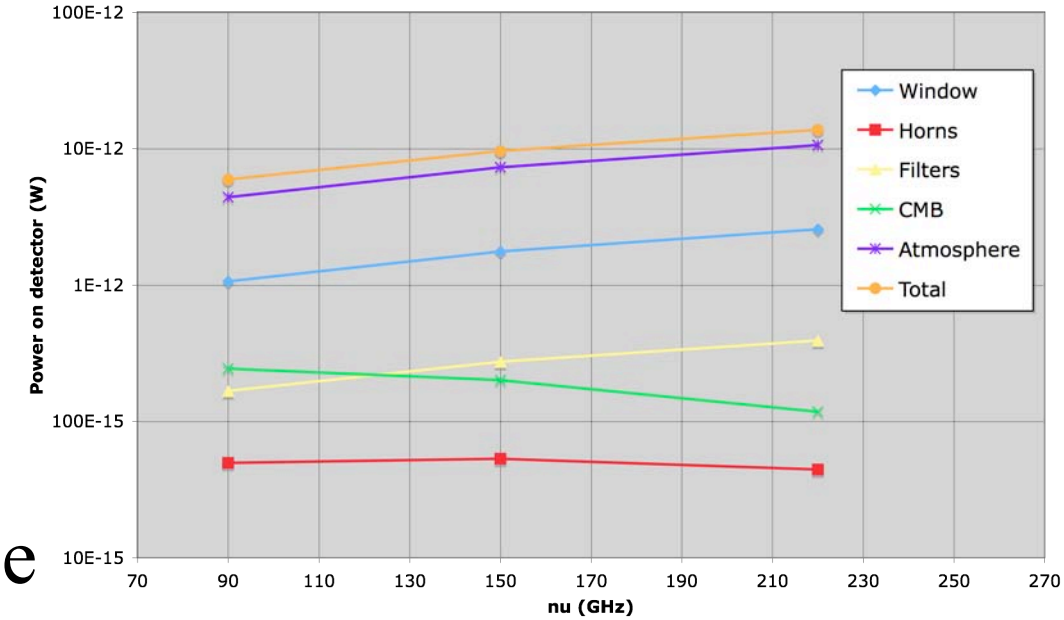
Site	T_{BB}
Chajnantor	16.5K
Chajnantor, θ=45°	21.4K
Dome-C	14K



Why is it an important factor?

CMB bolometric ground based experiment

- Power on detector from different sources:
  - **Atmosphere is dominant**
- Power = photon noise
  - **The lower, the better!**
  - **Space experiment (Planck-HFI): Background Limited Performances (BLIP)**



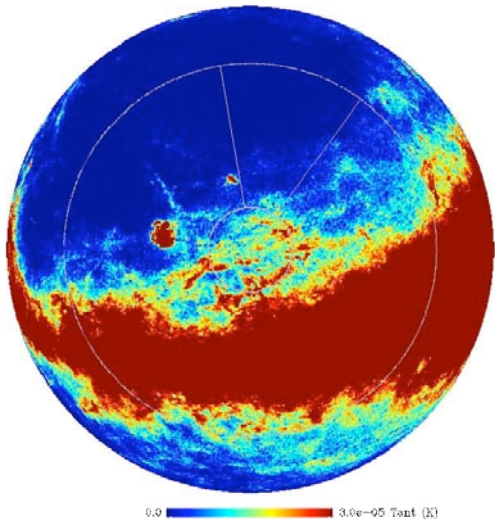
$$NEP_{h\nu}^2 \approx 2h\nu P_{back} \propto T_{atm}$$

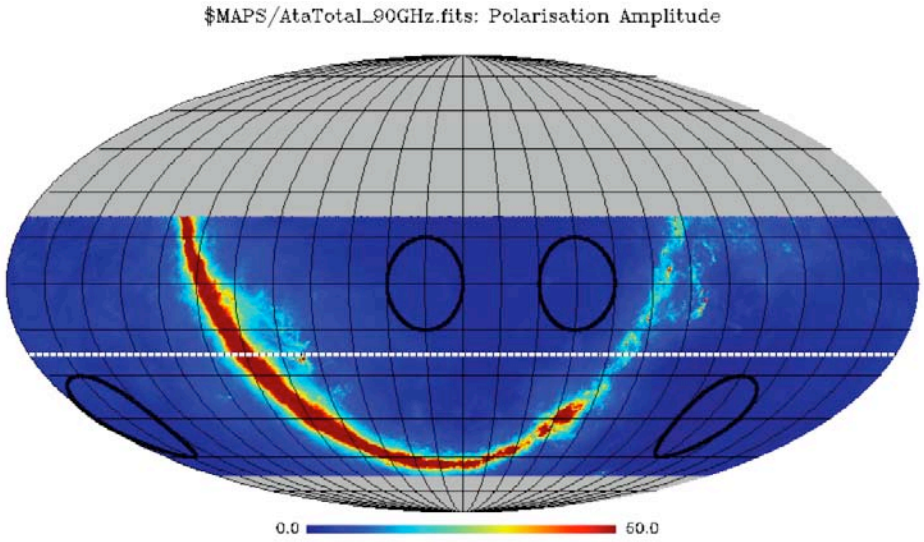
P_{back}=10pW $\Rightarrow$ $NEP_{h\nu}$= 5.10^{-17}W.Hz$^{-0.5}$
P_{back}=0.5pW $\Rightarrow$ $NEP_{h\nu}$=10^{-17}W.Hz$^{-0.5}$

Scanning strategy

- Dome-C:
  - **Latitude: 75°S**
  - **Easy to observe the same small region over long period…**
- Chajnantor:Example of CLOVER
  - **Latitude: 23° S**
  - **4 patches on the sky**
  - **Minimum elevation: 45°**

Field center (HHMM-DD)	rms polarized temperature (mK)		Time above elevation 45 degrees
	90 GHz	220 GHz	
0430-45	1.0	2.7	6.5h
0900-00	1.7	7.3	5.2h
1300-00	2.0	4.7	5.2h
2300-45	2.0	2.6	6.5h





(From A. Taylor, workshop Fundamental Physics With Cosmic Microwave Background Radiation, 2006)

CMB relative integration time

	Dome-C	Chajnantor
Scanning strategy	1	4
Sky temperature	1	1.2-1.5
Total	**1**	**4.8-6**

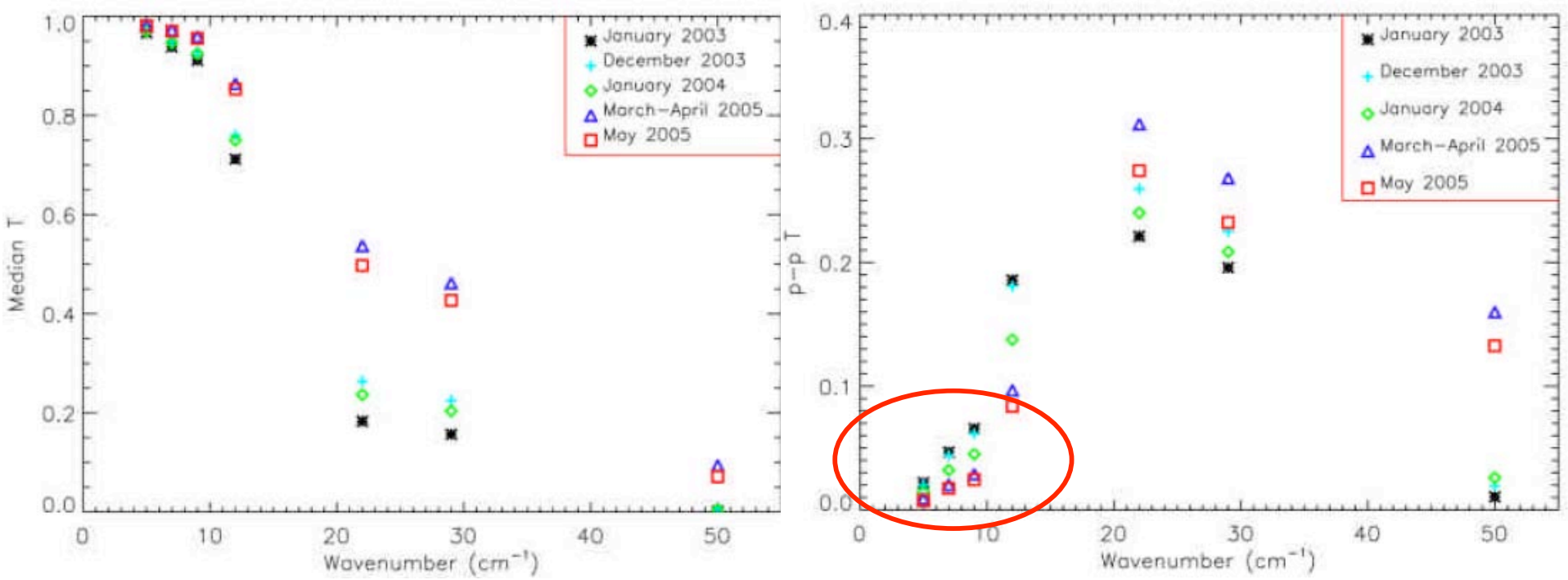
Naive approach: 1 year of CMB observation at Dome-C is equivalent to about 5 years at Chajnantor

Combination of the 4 fields: effect of scanning strategy is lower than the given factor 4

=> Global factor of 2 expected

Sky noise

- Measurements needed…
  - **Best transmission ⇒ smaller fluctuations**



(De Petris, ARENA site testing workshop)

Polarisation of the atmosphere

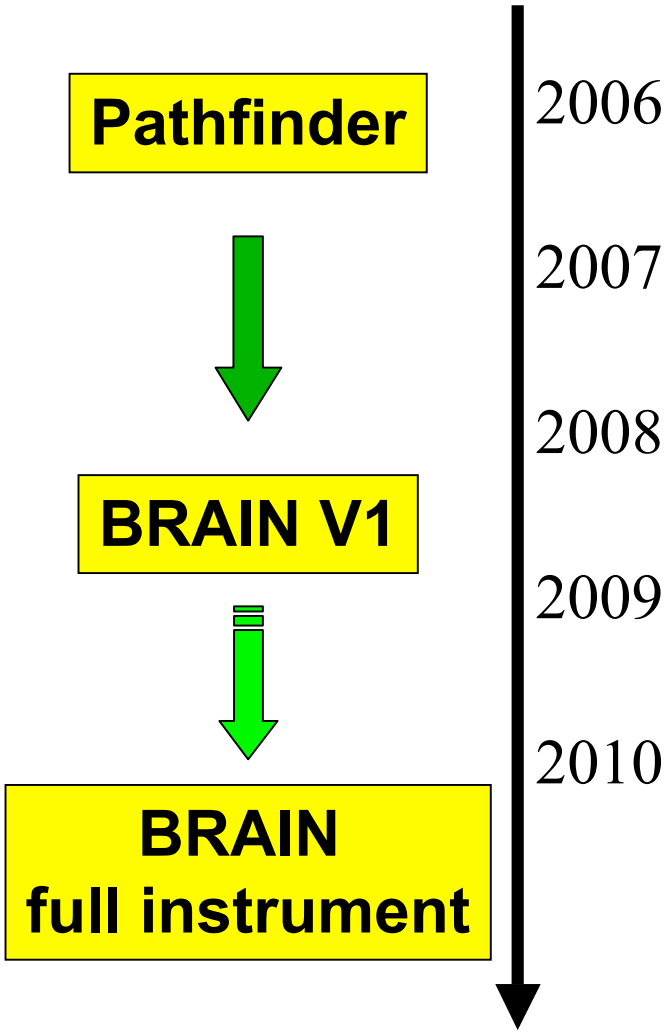
- 2 effects could cover the CMB signal:
  - **Zeeman splitting of oxygen line**
    - Produce circular and linear polarisation
    - Constant with time?
  - **Ice in the troposphere**
    - Back scattering of ground and lower atmosphere
    - Change of CMB polarisation
    - Could vary with time
- Polarisation is a differential measurement
  - **High rejection of common mode… to what level?**
- **Measurements needed!**
  - Has one CMB polarisation experiment detected polarisation effect of the atmosphere up to now?

3. The BRAIN (Background RAdiation INterferometer) collaboration

- Italy
  - Università di Roma La Sapienza
  - Università di Milano Bicocca
- United Kingdom
  - University of Wales Cardiff
  - University of Manchester
- France
  - AstroParticule et Cosmologie (APC)
  - Centre d'Etude Spatiale des Rayonnements (CESR Toulouse)
  - Centre de Spectroscopie Nucléaire et de Spectroscopie de Masse (CSNSM)
  - Laboratoire Instrument et Système d'Ile de France (LISIF Paris 6)
  - Institut d'Astrophysique Spatiale (IAS Orsay)

The BRAIN program

- Observation of the microwave sky from Dome-C, Antarctica
  - **CMB and foregrounds**
- Pathfinder:
  - **Site testing, logistics**
  - **Atmosphere characterisation**
  - **First installation in January 2006**
    - 370mK @ Dome-C!
    - First data at 150GHz
  - **Second campaign in December 2006**
    - About 1 month of observation!
- BRAIN
  - **Primordial B modes**
    - $50 < l < 200$
  - **Bolometric interferometer**



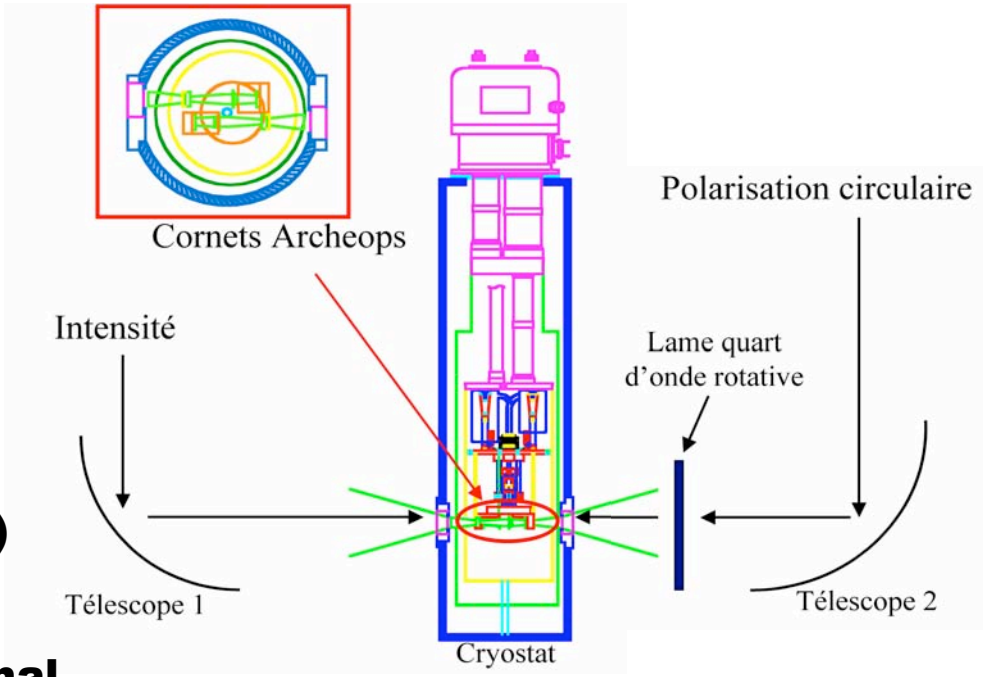
The Pathfinder

Objectives:

1. To demonstrate the autonomous operation of a 0.3K cryogenic system during Antarctic winter
2. To demonstrate the remote control of the experiment from Europe
3. To measure the emission both in intensity and polarisation from the atmosphere at 150GHz during winter

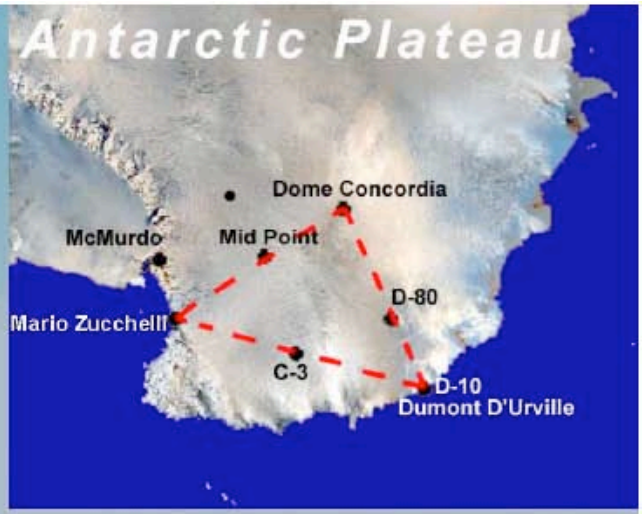
The Pathfinder

- 4K: Pulse Tube cooler
- 300mK: ^{7}He fridge
- Two bolometers
  - **Intensity and polarisation**
  - **Imager (not interferometer)**
- Rotating quarter wave plate
  - **Modulate the polarised signal**
- Installed at Dome-C in January 2006 and December 2006
  - **350mK reached**
  - **About a month of observation**
  - **Data being processed**



BRAIN at Dome C

Lat: 75° 06' SLon: 123° 23' E
Altitude 3230m osl
Main air temperature -50.8 °C
Typical monthly average air temperature in summer -30 °C
Typical monthly average air temperature in winter -60 °C
Mean wind speed 2.8 m/s 5.4 knots
Mean air pressure 645 hPa
Yearly precipitation range (snow) 2-10 cm



BRAIN site

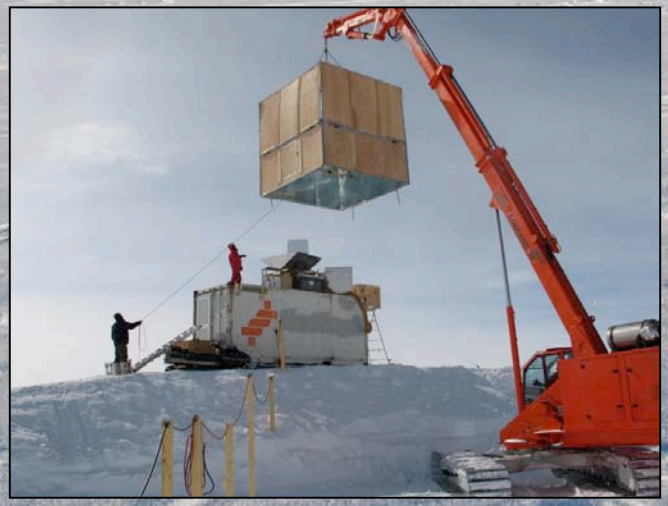
Is Dome-C the best site for B-modes measurements?

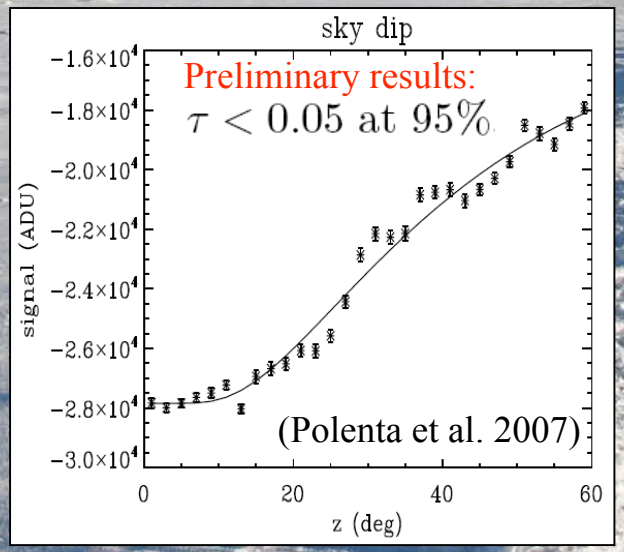
BRAIN

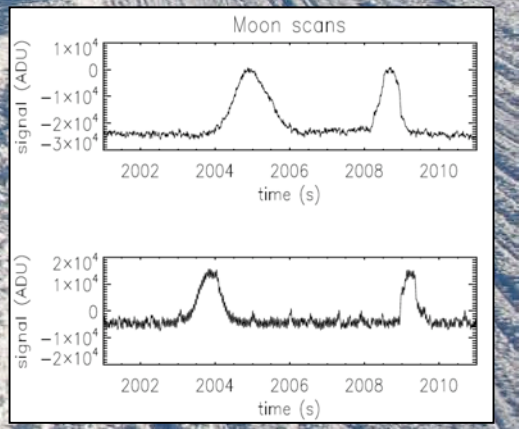
Pathfinder

(Dec. 11th 2006)

Observations done:
- Sky dips
- Moon
- CMB



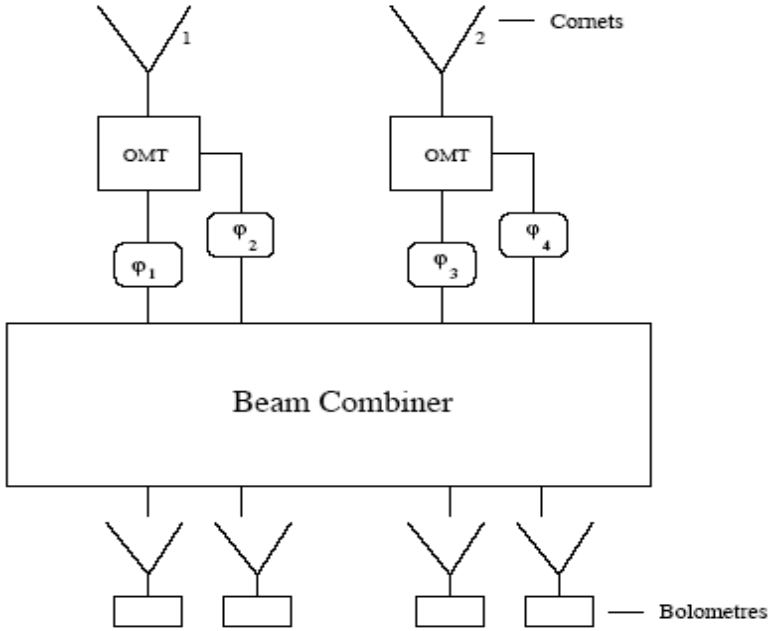




BRAIN: Principle of bolometric interferometry

- For one baseline:

$$\begin{aligned}\mathcal{P}_{B.C.} = \frac{1}{4}\Big\{ & 2I + U[\cos(\varphi_1 - \varphi_2) + \cos(\varphi_3 - \varphi_4)] \\ & + V[\sin(\varphi_1 - \varphi_2) + \sin(\varphi_3 - \varphi_4)] \\ & + |\mathcal{V}_Q|[\cos(\phi_Q - \varphi_1 + \varphi_3) - \cos(\phi_Q - \varphi_2 + \varphi_4)] \\ & + |\mathcal{V}_I[\cos(\phi_I - \varphi_1 + \varphi_3) + \cos(\phi_I - \varphi_2 + \varphi_4)] \\ & + |\mathcal{V}_U[\cos(\varphi_2 - \varphi_3 - \phi_U) + \cos(\varphi_1 - \varphi_4 - \phi_U)] \\ & + |\mathcal{V}_V|[\sin(\phi_V - \varphi_2 + \varphi_3) - \sin(\phi_V - \varphi_1 + \varphi_4)]\Big\}\end{aligned}$$

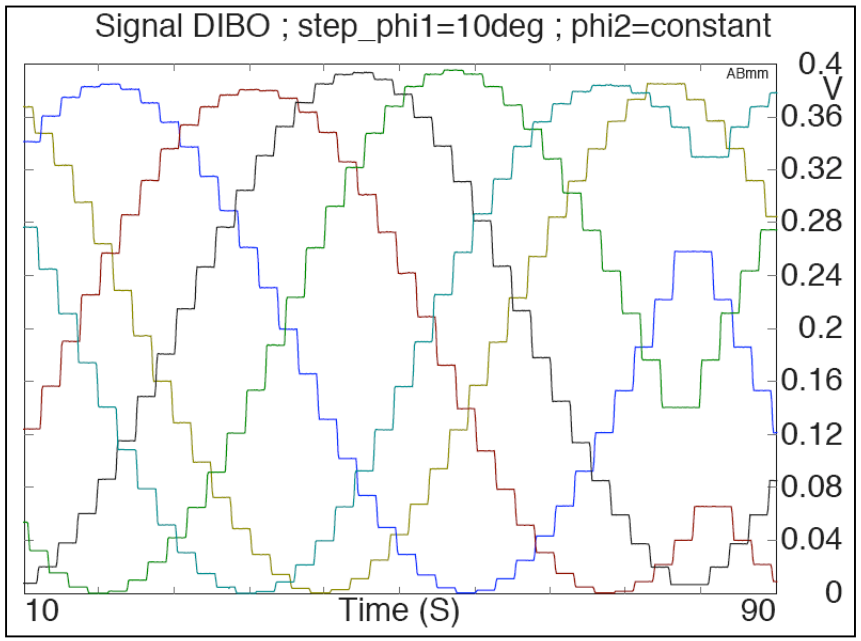


- Can be generalised to N baselines
- Link with B modes: $\mathcal{V}_{\mathrm{U}} \equiv a^{B}\left(\vec{v} = \vec{u} = \vec{D}_{\lambda}\right)$

Demonstration of Bolometric Interferometry (DIBO)

- Single baseline
- Only one polarisation state
  - **No OMTs**
- Commercial components
  - **300K components**
  - **All but the phase shifter can be used on BRAIN v1**
- 4K bolometer or VNA

Validation of the detection method!

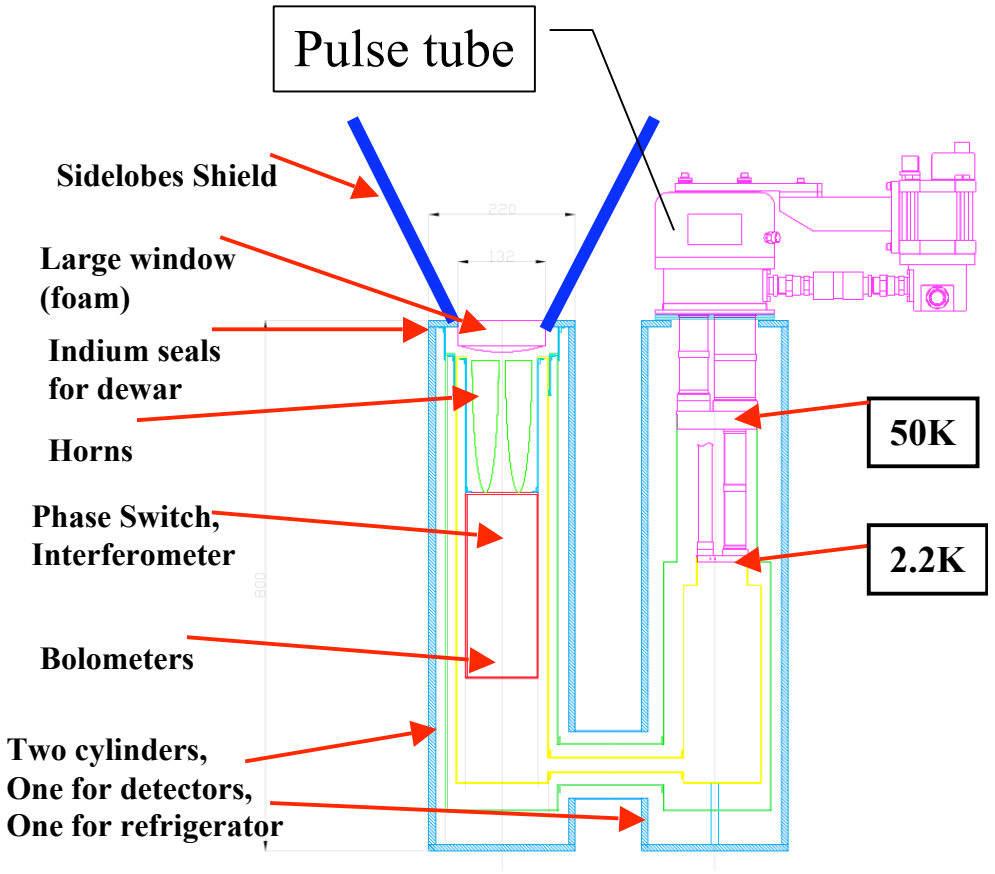


Why bolometric interferometry?

1. Same sensitivity as an imager
   - **Same sky coverage**
   - **Number of detectors determined by the number of baselines couples of same length and same direction**
2. Natural modulation of the polarised signal
   - **Phase modulation instead of polarisation rotation**
3. Direct measurement of the Fourier modes of all Stokes parameters
   - **Direct measurement of E and B**
4. Systematic effects are different
   - **No mirrors, use of the maximum collecting area**
   - **Interferometer: reduction of the atmospheric signal**
5. High sensitivity - Data processing less complex
   - **Low temperature bolometers: high sensitivity**
   - **Interferometer: direct measure of Fourier modes**

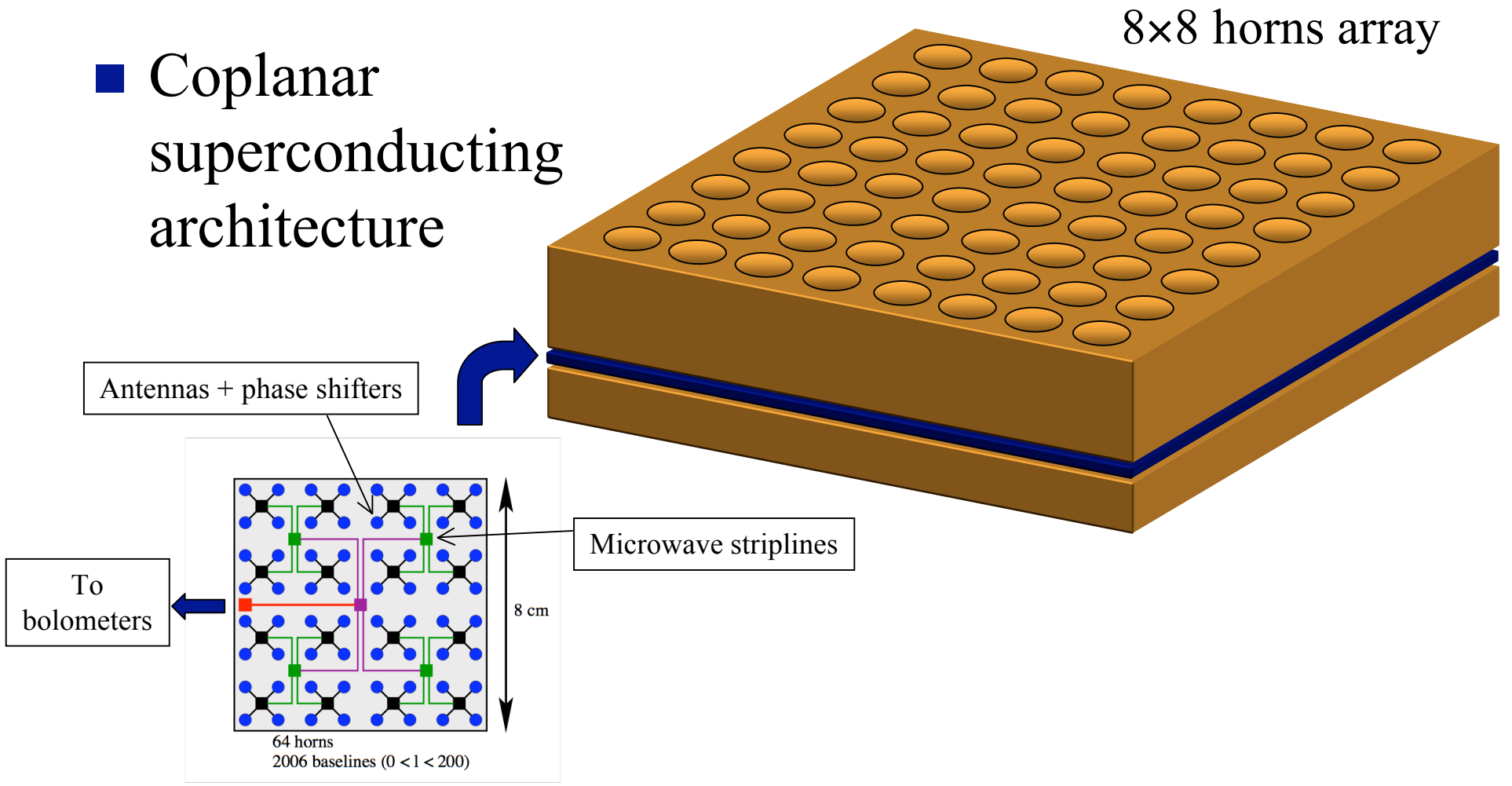
BRAIN full size

- Cryogenics with no LHe
  - **Pulse Tube: 4K**
  - **Continuous operation**
  - **Power needed: 3.5kW**
- 3 channels: 90GHz, 150GHz and 220GHz
- 16x16 horns
  - **120 independent baselines**
- 300mK bolometers



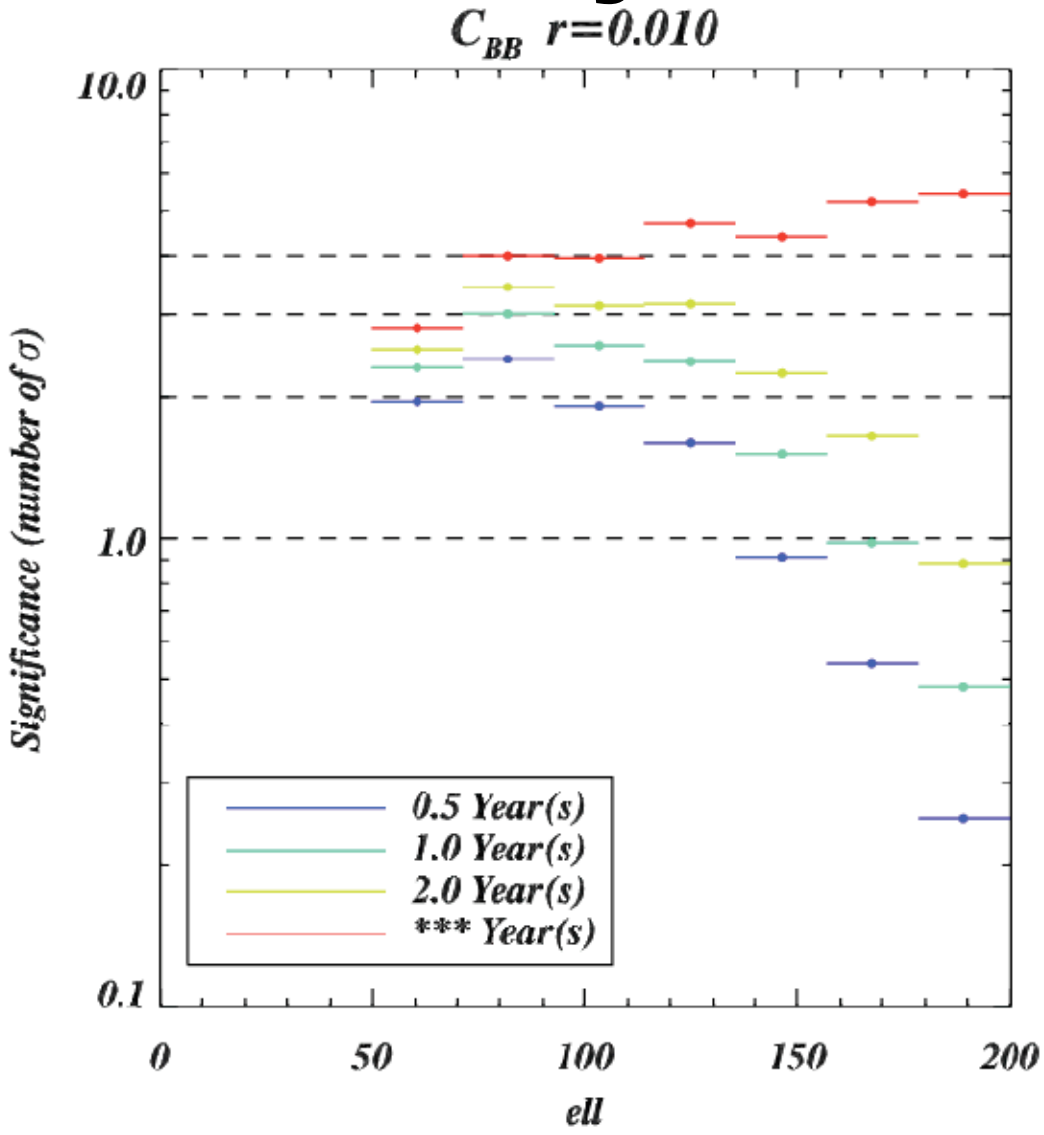
BRAIN detection block

- Coplanar superconducting architecture



BRAIN full size sensitivity to B-modes

- r=0.01 detectable at 3σ
- Instrument simulation and optimisation is ongoing…



Conclusions

- CMB observation from Dome-C
  - **Gain in integration time wrt Chajnantor**
  - **Measurements needed:**
    - Sky noise
    - Polarisation of the atmosphere
- BRAIN
  - **Pathfinder: site characterisation both in intensity and Polarisation**
  - **Bolometric interferometry: a new tool to study CMB polarisation**