
101°
CONGRESSO
DELLA
SOCIETÀ ITALIANA DI FISICA

BOLOMETRIC INTERFEROMETRY IN THE QUBIC EXPERIMENT

DIPARTIMENTO DI FISICA

SAPIENZA UNIVERSITÀ DI ROMA

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on behalf of the QUBIC collaboration

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Outline

1.QUBIC: science and scientific context

2.Bolometric Interferometry B.I.

3. Experiment overview

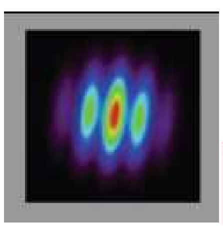
4. Optical Analysis

Q & U Bolometric Interferometry for Cosmology

APC Paris, France
IAS Orsay, France
IEF Orsay, France
CSNSM Orsay, France
IRAP Toulouse, France
Maynooth University, Ireland
Università di Milano-Bicocca, Italy
Università degli studi, Milano, Italy
Università La Sapienza, Roma, Italy
University of Manchester, UK
University of Cardiff
Richmond University, USA
Brown University, USA
University of Wisconsin, USA

substantial participation of NIKHEF, University of Leiden and TNO (The Netherlands) under discussion

arXiv: 1010.0645 Astroparticle Physics 34 (2011) 705-71

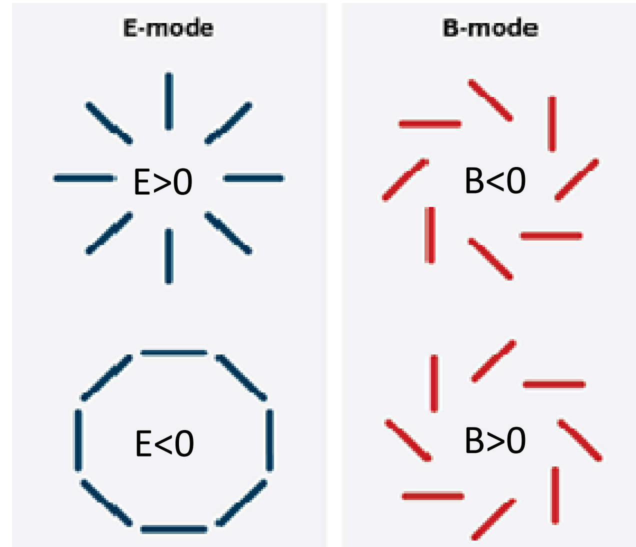


Constrain the B-modes down to r=0.01 @ 95% of confidence level

Why we want to measure B modes?

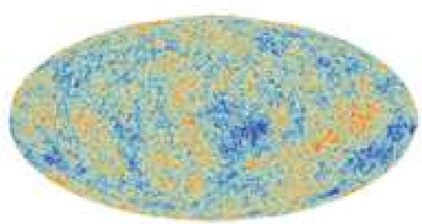
Inflation leaves a peculiar footprints in the CMB sky polarisation pattern

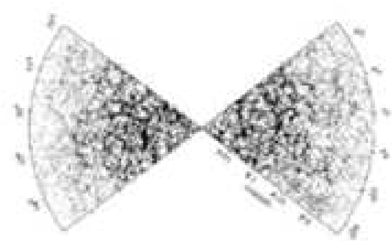
- ❑ E-mode ⟶ gradient component (even)
- ❑ B-mode ⟶ curl component (odd)



ζ <u>Scalar perturbations</u> (density fluctuations) ⟶ only E modes

Fluctuations we observe today originated from quantum fluctuations generated during inflation





h_{ij} <u>Tensor perturbations</u> (gravitational waves) ⟶ both E and B modes

Gravitational waves originated from quantum fluctuations generated during inflation

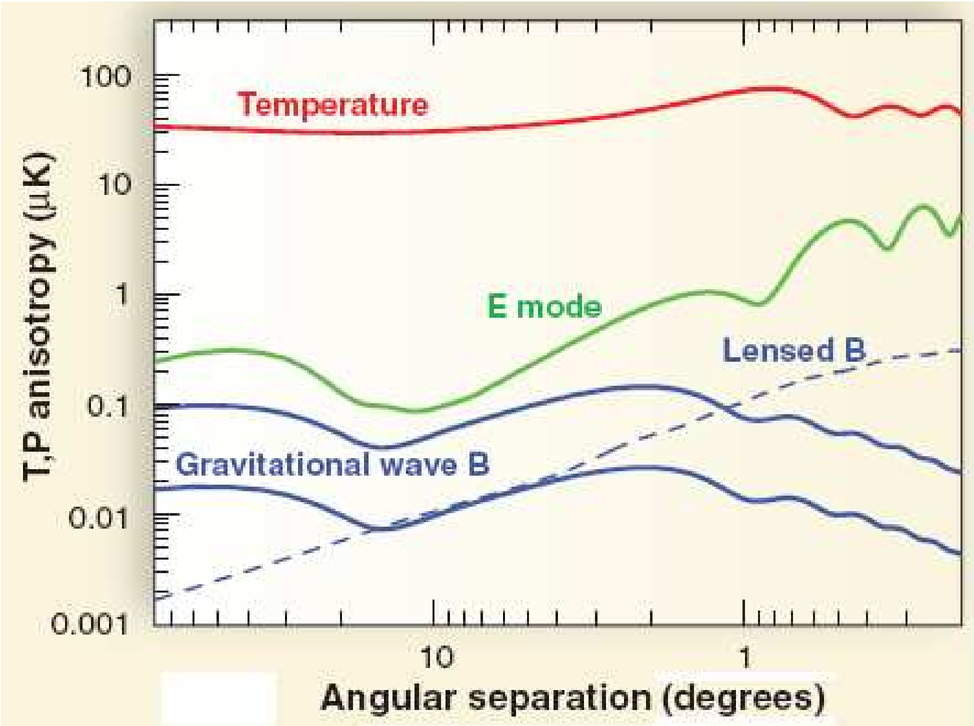
B modes detection in CMB polarization pattern is the Holy Grail for Cosmology

B modes are the smoking gun for Inflation theory

Measure of the tensor to scalar ratio at the energy scale of Inflation

$$\boxed{r_{ij} = \frac{h_{ij}}{\zeta}}$$

$$V^{\frac{1}{4}} = 1.06 \times 10^{16}\, GeV\, \left(\frac{r_{ij}}{0.01}\right)^{\frac{1}{4}}$$



Challenges in the primordial CMB B-modes quest

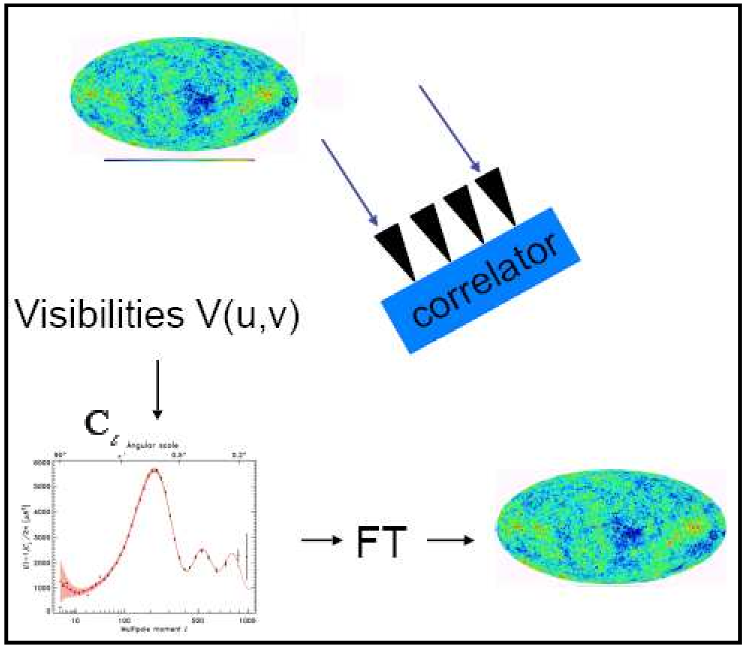
✓ Sensitivity: B modes are about ten time fainter than E modes (amplitude could be very small), no correlation with Temperature for their handedness

✓ Foreground contaminations: need to be removed using multi-wavelength detectors

✓ Systematic effects: leakage of T into E and B (T>>E>>B)

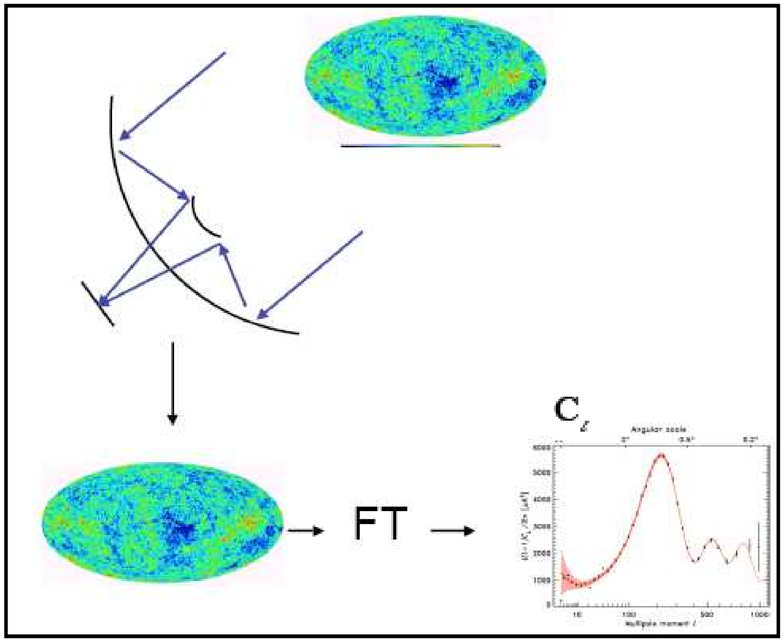
INTERFEROMETERS *vs* IMAGERS

INTERFEROMETERS
(CBI, DASI Interferometer)



vs

IMAGERS
(BICEP, EBEX, SPIDER, QUITE, PolarBear)



- better **control of the systematics**
- no telescope → low ground pick-up and cross polarization
- angular resolution defined by antennas positions
- limited number of channels and amplifier noise

- **good sensitivity** thanks to large bolometers arrays (wide band, low noise)
- systematic induced by telescope's presence
- atmospheric noise → accurate scan strategy

Bolometric Interferometry

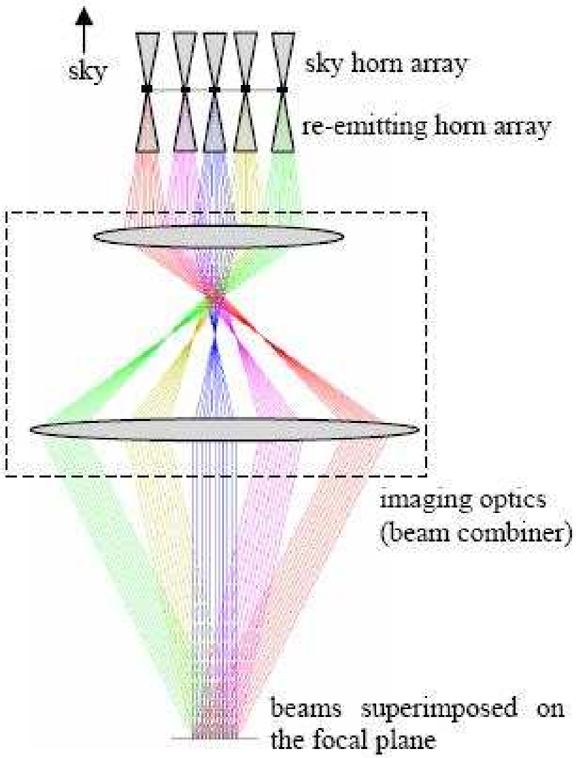
A novel technique that combines the advantages of the interferometers in terms of control of the systematics with high sensitivity of cryogenic bolometers

Comparable sensitivity as an imager

Direct measurement of the Fourier modes of all Stokes parameters

High Sensitivity & Systematics control

Fizeau combination: All to one



✓QUBIC operates as an adding interferometer : Fizeau approach

✓Phase difference is present both before and after incoming antennas: external phase difference gives the relation visibility FT sky-image / internal phase the same but FT^{-1}

✓Fizeau combination allows imaging in an interferometer where the images are modulated by synthesized beam produced by interference pattern

✓Horns aperture act as diffractive aperture pupils producing a ''spatial filtering'' of incoming radiation

$$P = |E_1 + E_2 + \ldots E_N|^2 = |E_1|^2 + |E_2|^2 + \underline{E_1 \cdot E_2^*} + \ldots$$

Visibilities

QUBIC as a Synthetic imager

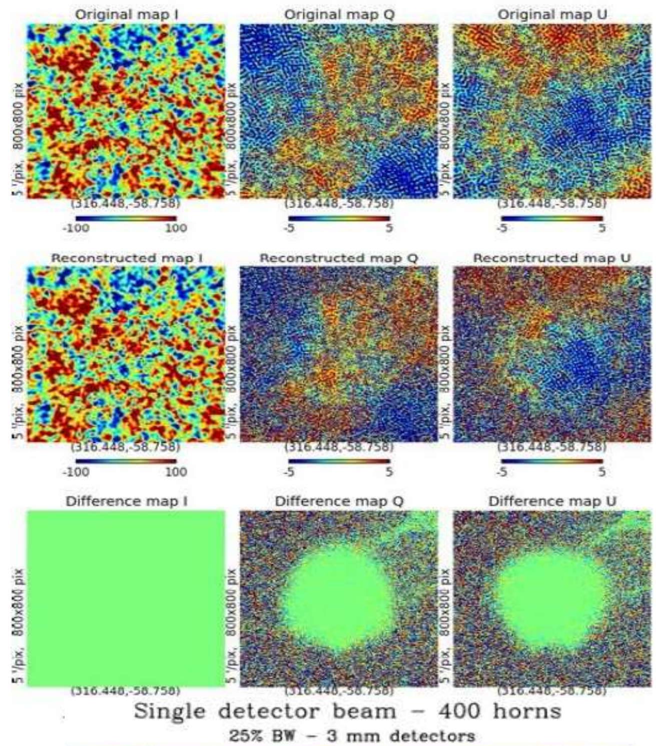
- QUBIC Beam Combiner alone can be used as a telescope (uniformly illuminated pupil) accepted N=FOV/(λ/D)² independent Airy spots

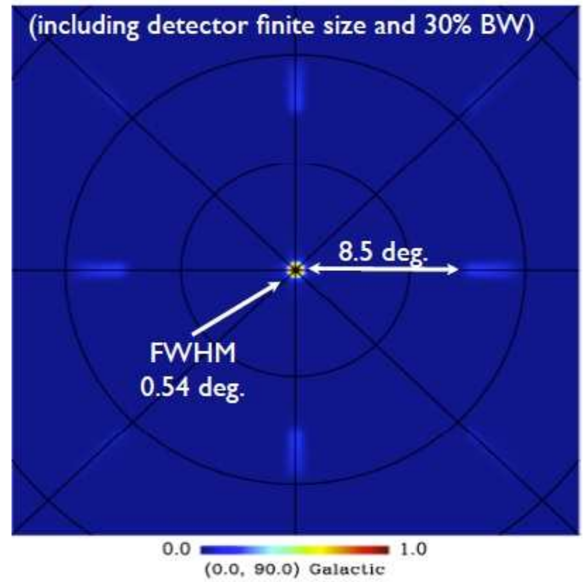
- Horns are diffractive (single-mode) apertures that make spatial filtering. The entrance pupil is a square array of gaussian-illuminated apertures, whose far-field pattern, produced by the telescope, is QUBIC synthetized beam

- On a given focal plane pixel, the synthetic image is the convolution of sky signal (Q,U) and synthetized beam

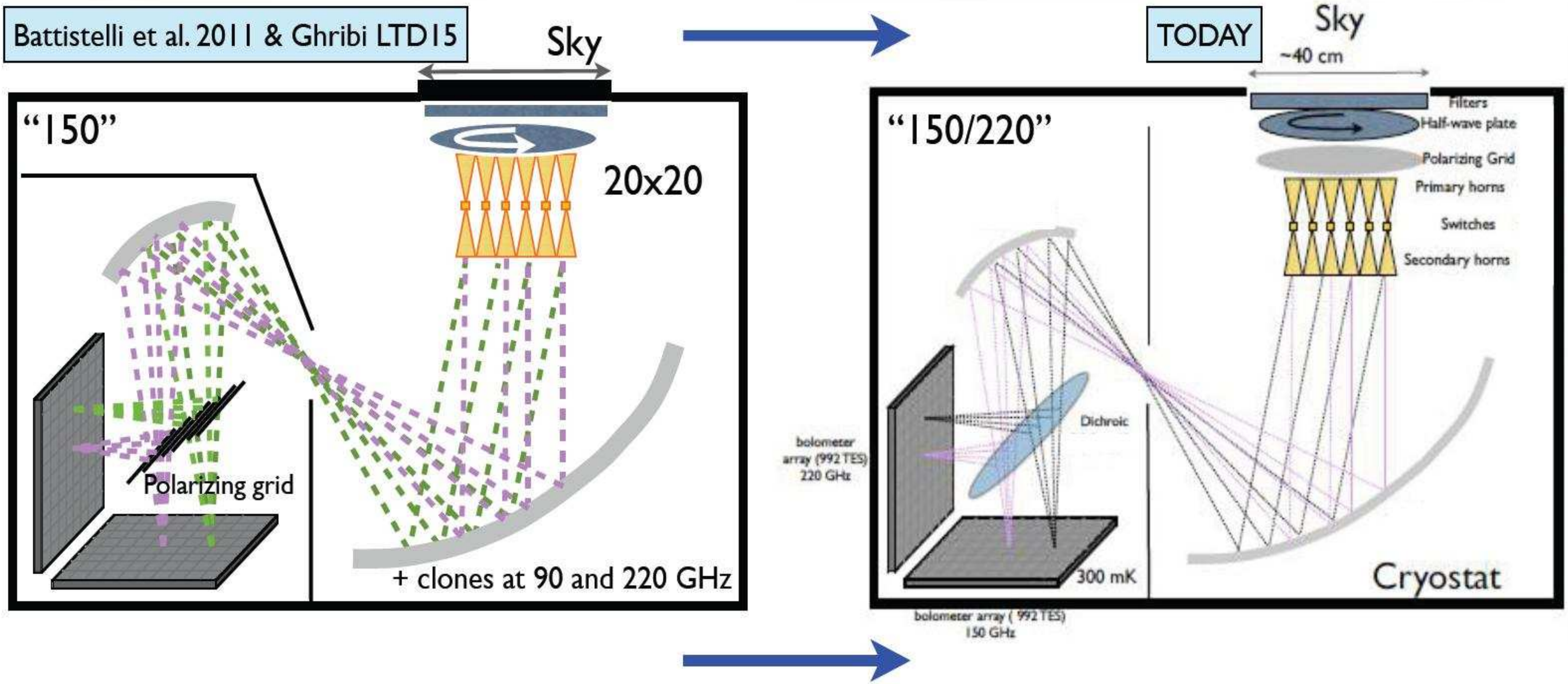
$$S_X(\vec{d}_p) = \int X(\vec{n}) B_S^p(\vec{n}) d(\vec{n})$$

X={Q,U} and B^p_s is the synthetic beam at pixel p





QUBIC Design in nutshell



March 2014/July 2014: discussions & collaboration decision

After Planck claim on BICEP2 results: dual band configuration 150/220 GHz

- ✓Increasing of the scientific impact of the experiment
- ✓Reduce as much as possible modifications of the instrument concept & sub-systems

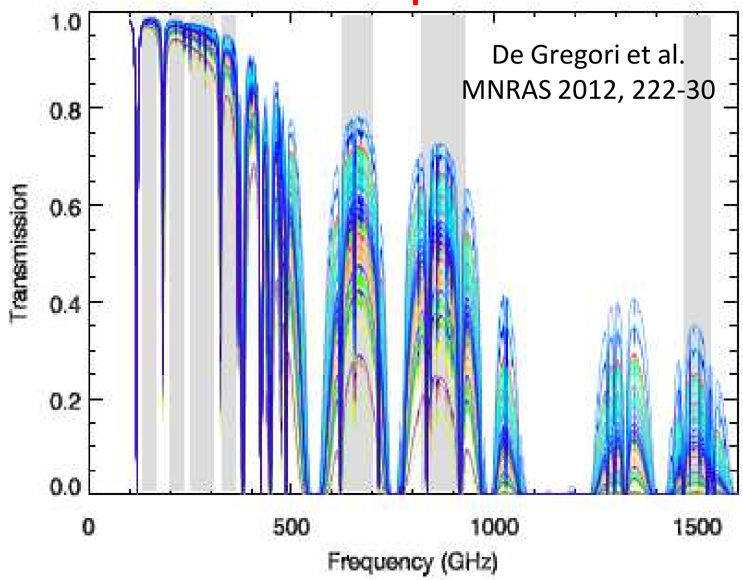
QUBIC dual band configuration @ Dome-C /2yrs (30% on sky coverage) r<0.05 (95% CL) in presence of dust (no ext.)

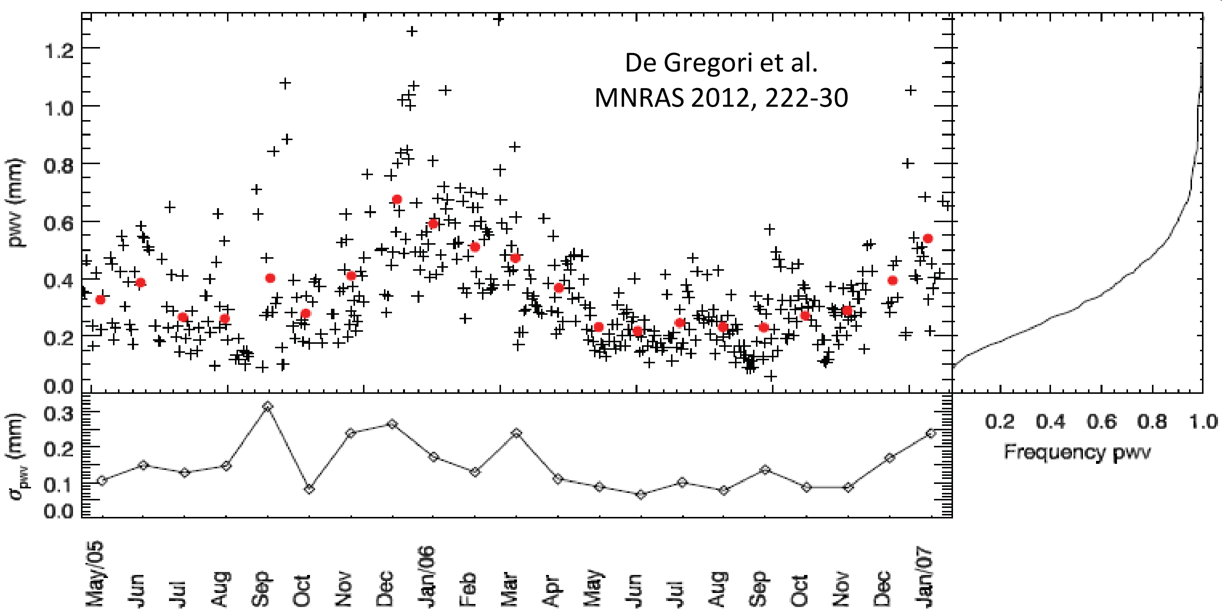
QUBIC Site: Dome-C

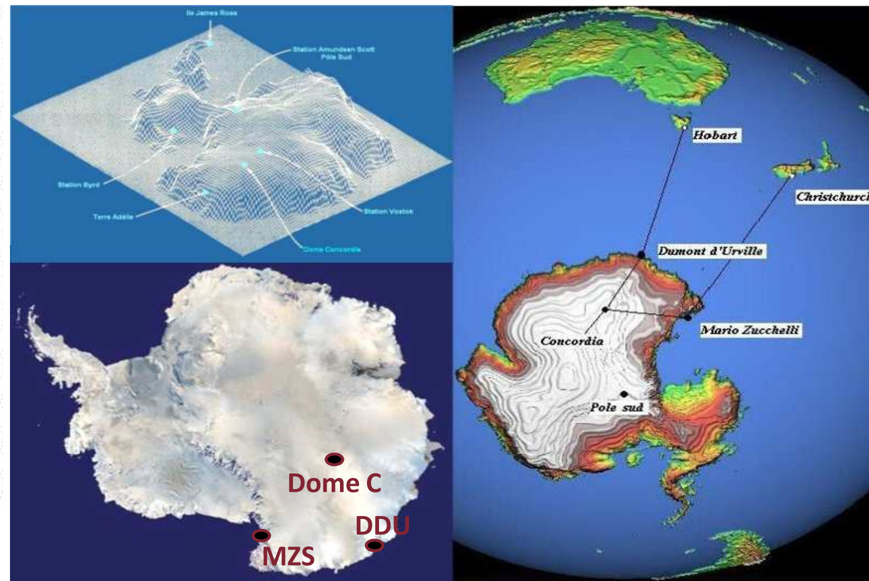
De Petris at al. SIF Communication

Dome C site, Antarctica, is one of the best site for millimetre and sub-millimetre astronomy on Earth thanks to its low value of Precipitable Water Vapour (pwv)

Transmission Spectra from ATM







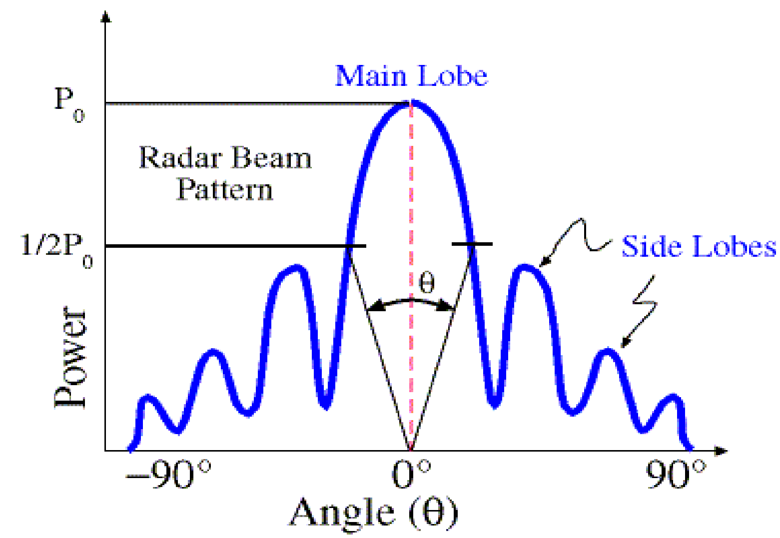
123° 23' 42'' E, 75° 06' 06'' S, 3233m asl

QUBIC Shielding Analysis

Analysis relate to the necessity of shielding the QUBIC experiment in order to reduce unwanted radiation on detectors coming from different contamination sources

The analysis has been realized with the support of the simulation software ***GRASP*** and ***CHAMP*** developed by TICRA Corp.

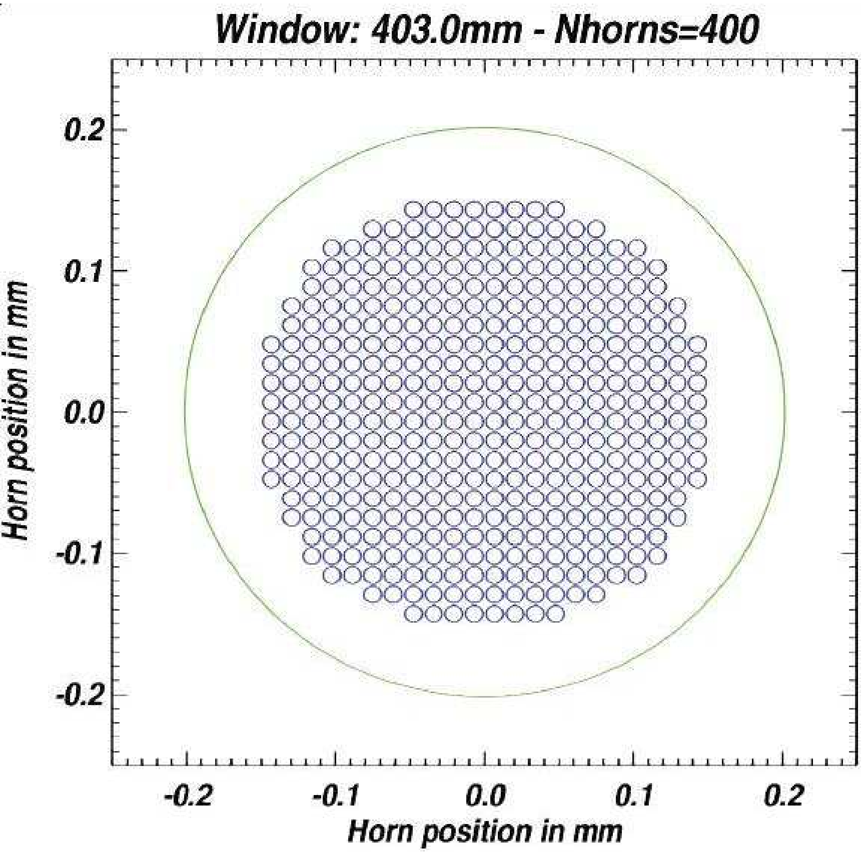
Study of the beam pattern of the instrument including sidelobes concerning spillover contributions



Goal of this analysis is the determination of the best geometrical configuration for the forebaffle and ground shield that should be installed in the QUBIC experiment

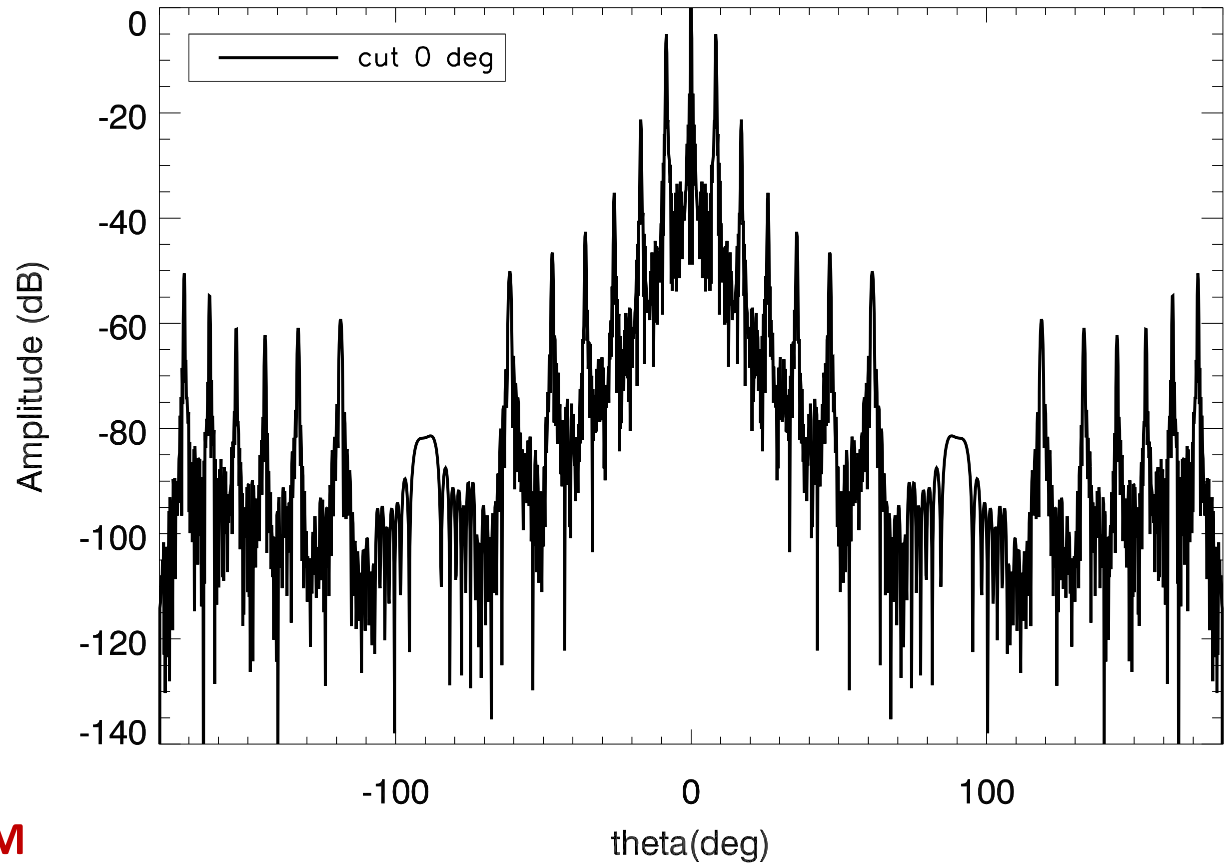
Simulations have been performed using **MultiGTD** approach (i.e. Geometric Theory of Diffraction) suitable when the dimensions of the reflectors are hundreds times of wavelength and **Method of Moments** (MoM) approach (i.e. surface currents calculation)

QUBIC Shielding Analysis



Circular 20x20 horns array, 14deg FWHM

Synthesized beam

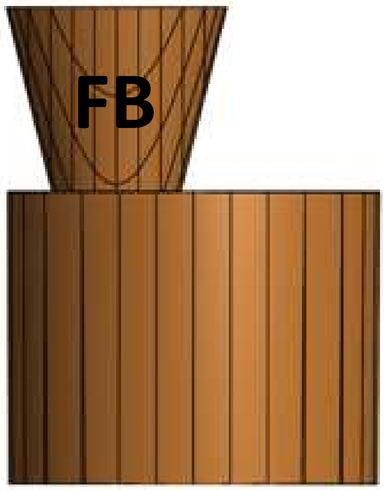


max baseline B_{max} = 300 mm
min baseline $B_{min} = d_h$ = 13.8 mm

Peaks angular distance: λ / B_{min} = 7.5°
Peak angular size: λ / B_{max} = 0.57°

QUBIC Shielding Analysis

In order to reduce spurious radiative contributions inside the QUBIC focal plane, have been investigated different solutions to correctly select the number and the geometry of the shields for the QUBIC experiment

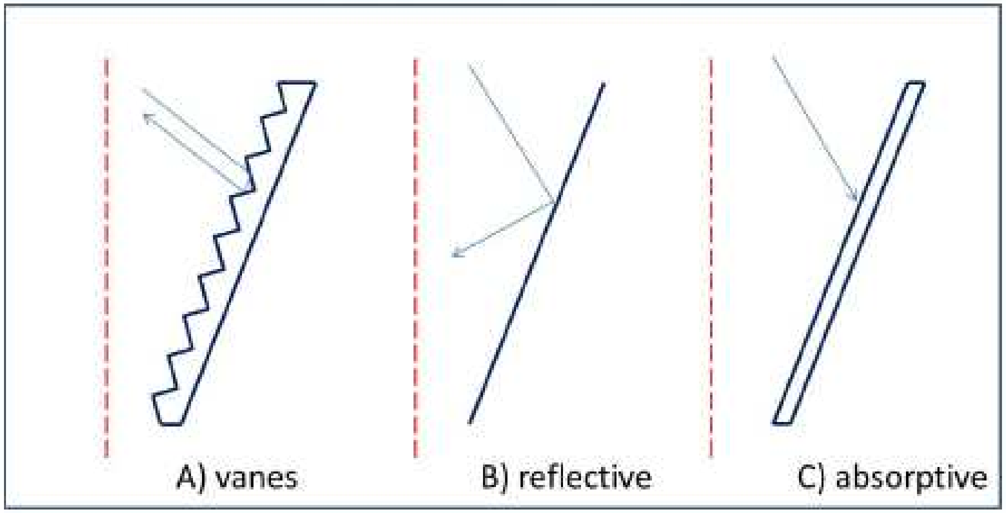


Forebaffle (FB)

- Fixed on cryostat's window 100 mm above feed horns array (TBD)
- Conical / cylindrical shape
- Conical shield with aperture angle equal to 2*$FWHM$ of single horn = 14°
- 350 mm base diameter and 1m height (TBD) has been investigated

Simulations have been performed considering reflective and absorptive inner surface of the FB , other possible configurations, like vanes, are under investigation

Shields inner surface

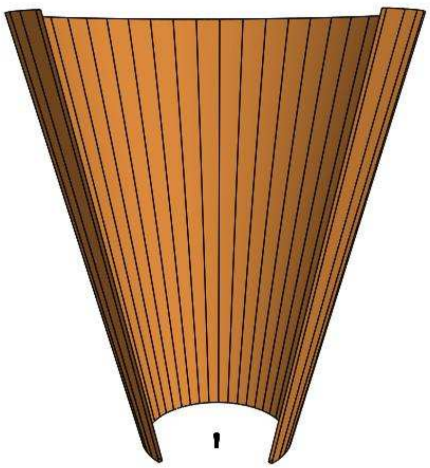


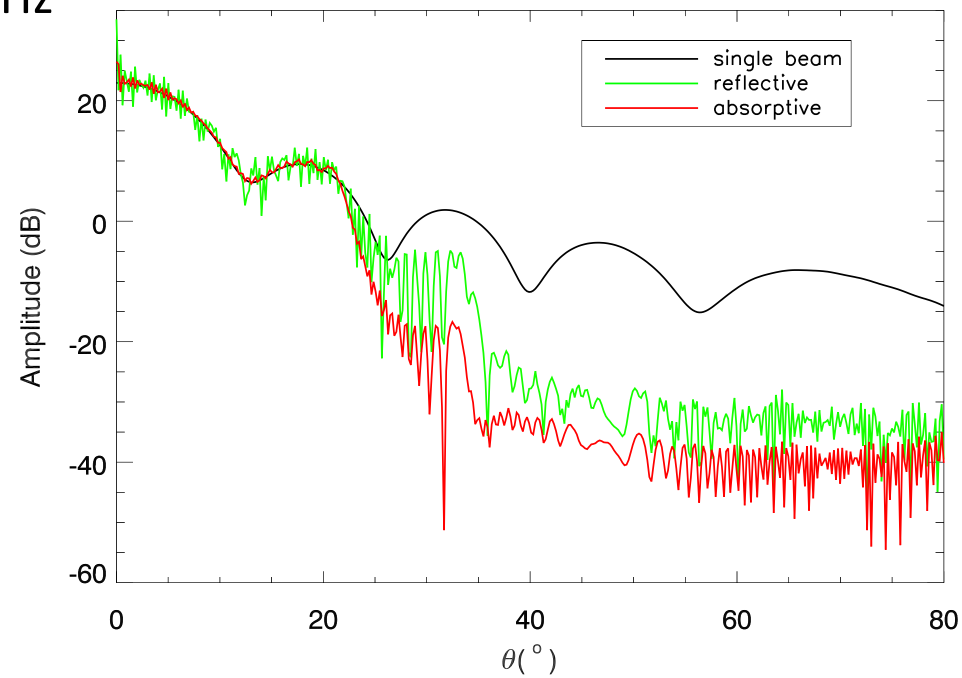
Absorptive inner sheet: 10mm thickness / n = 1.82 / tan loss = 0.057

QUBIC Shielding Analysis

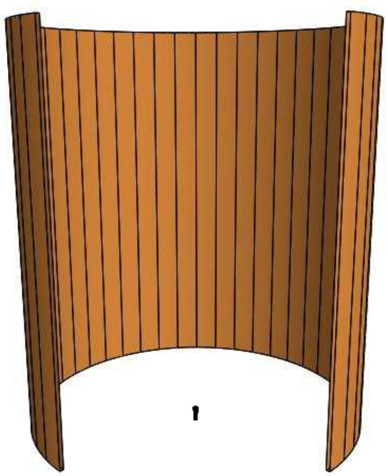
MGTD & MoM analysis performed @ 150GHz

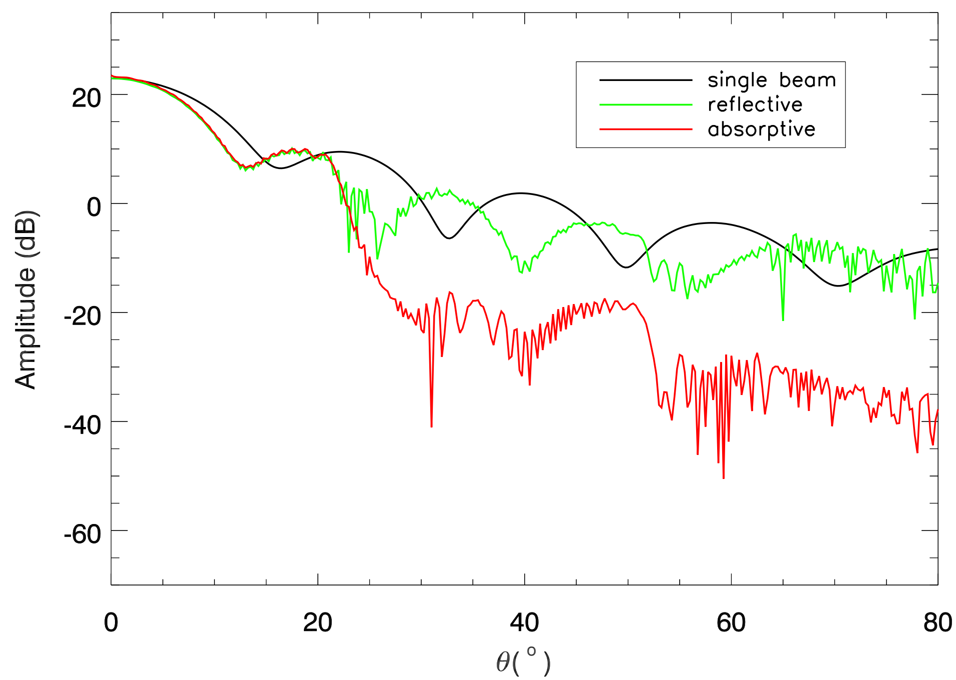
Conical Shape





Cylindrical Shape

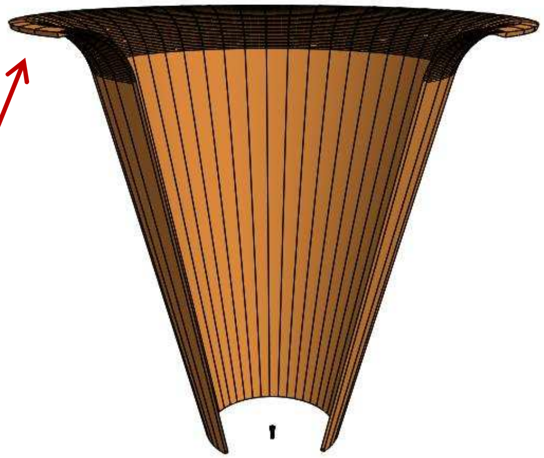


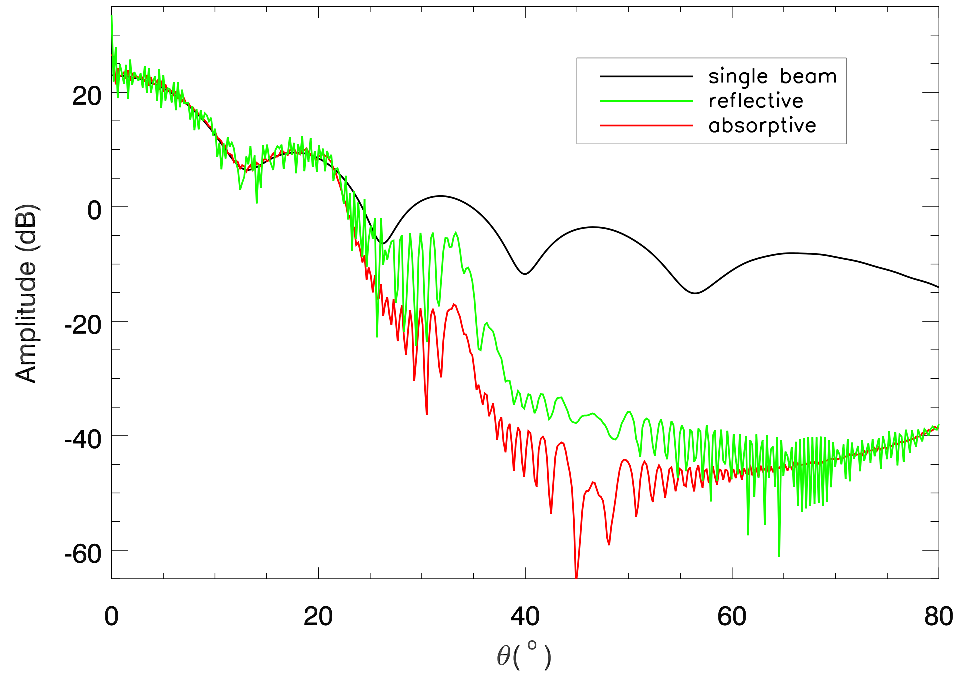


QUBIC Shielding Analysis

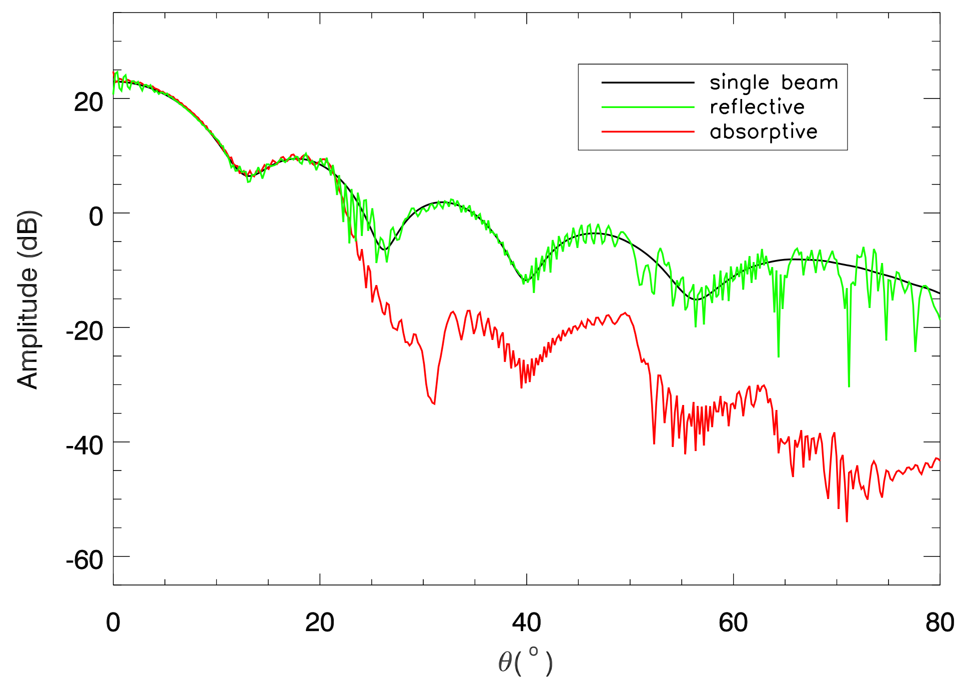
MGTD & MoM analysis performed @ 150GHz

Conical Shape
+
Flare 50mm





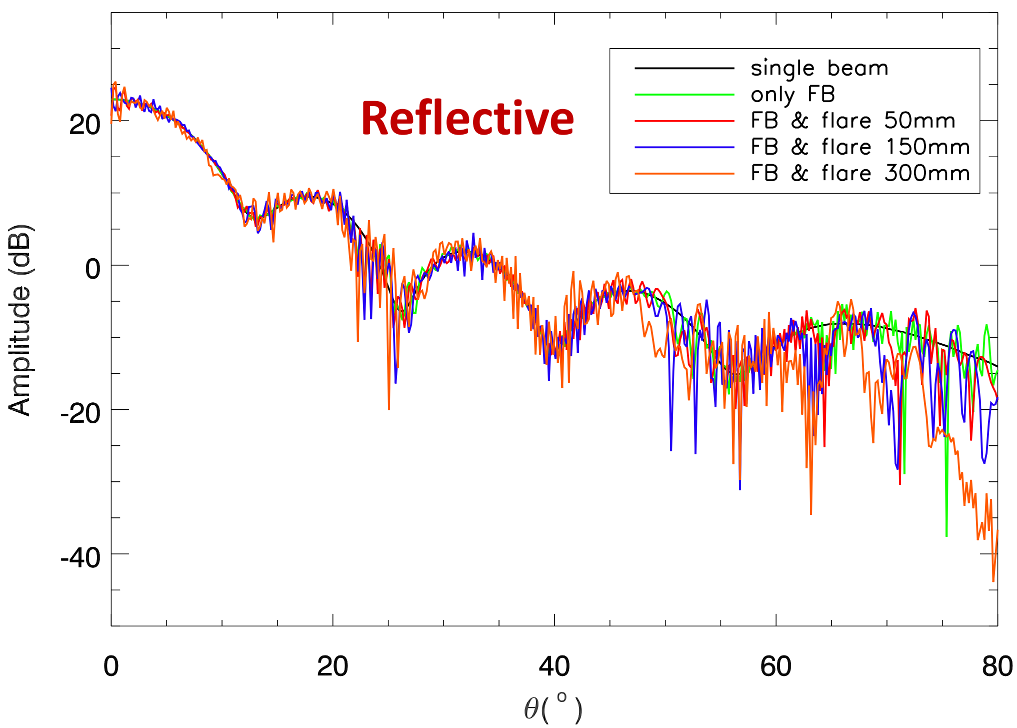
Cylindrical Shape
+
Flare 50mm

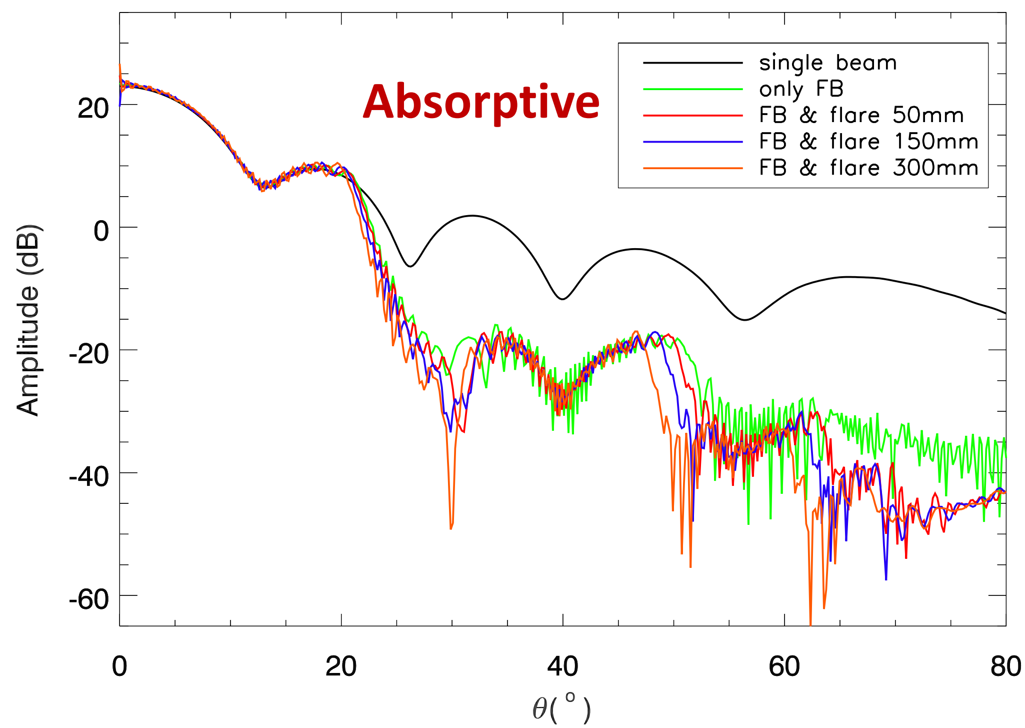


QUBIC Shielding Analysis

MGTD & MoM analysis performed @ 150GHz

Cylindrical shaped shield assuming 3 different flare's curvature radius (50-150-300mm) for reflective and absorptive inner surface





QUBIC Shielding Analysis

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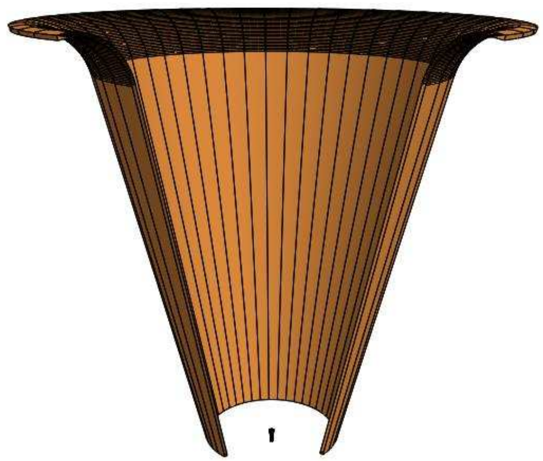
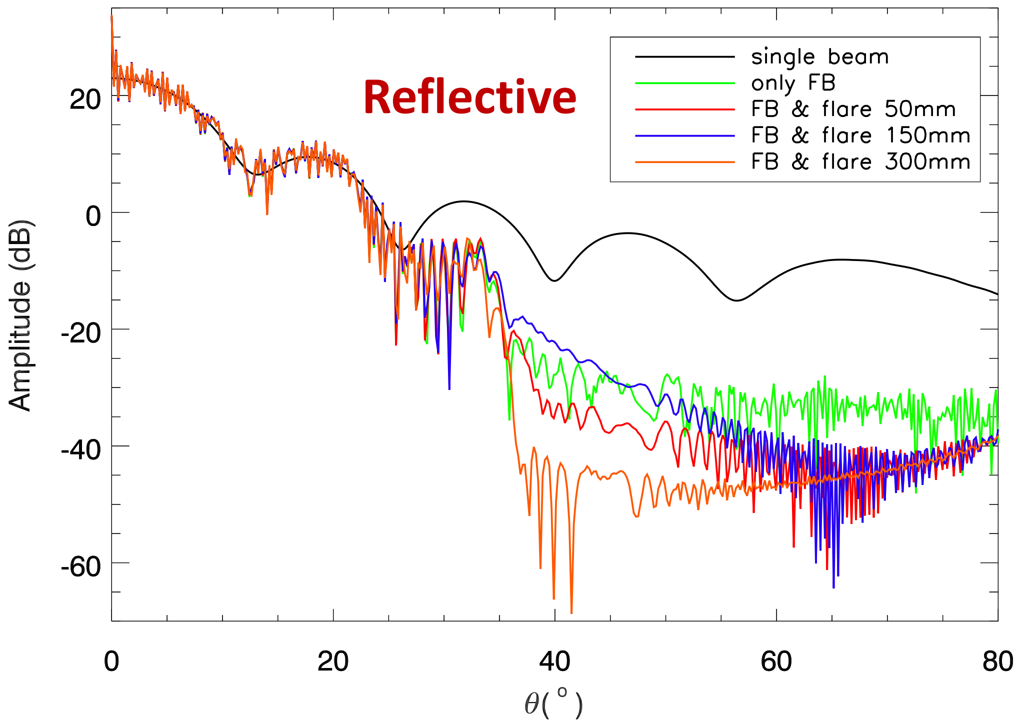
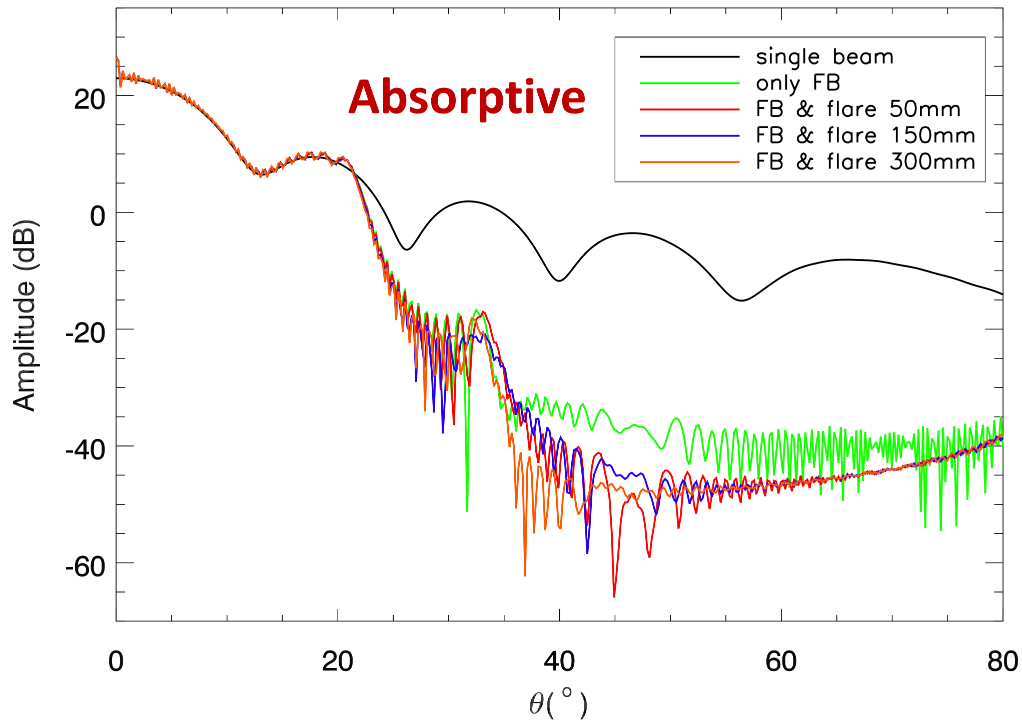


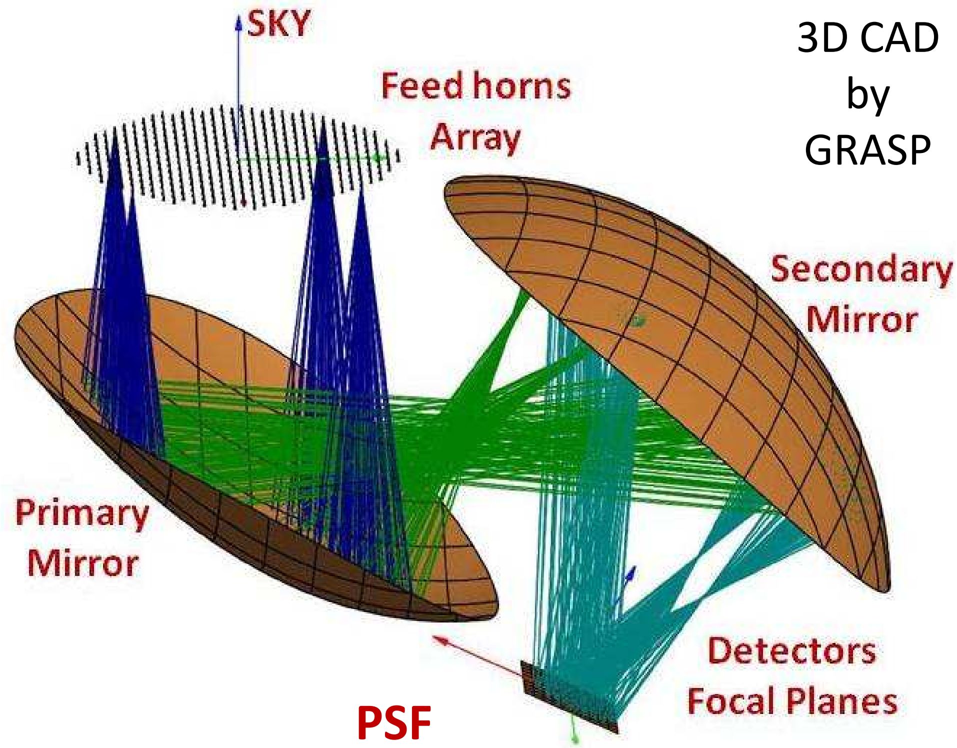




QUBIC Beam Combiner

Beam Combiner characteristics

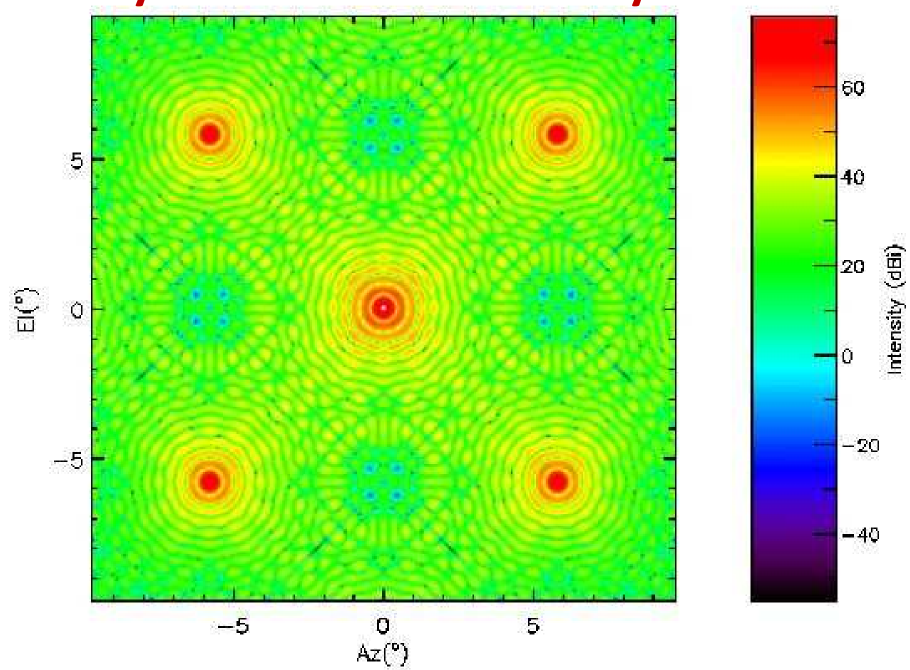
- ✓Compensated off-axis Gregorian design
- ✓ 300 mm focal length
- ✓ Rush & Dragone condition verified
- ✓ telecentric design (distant exit pupil)



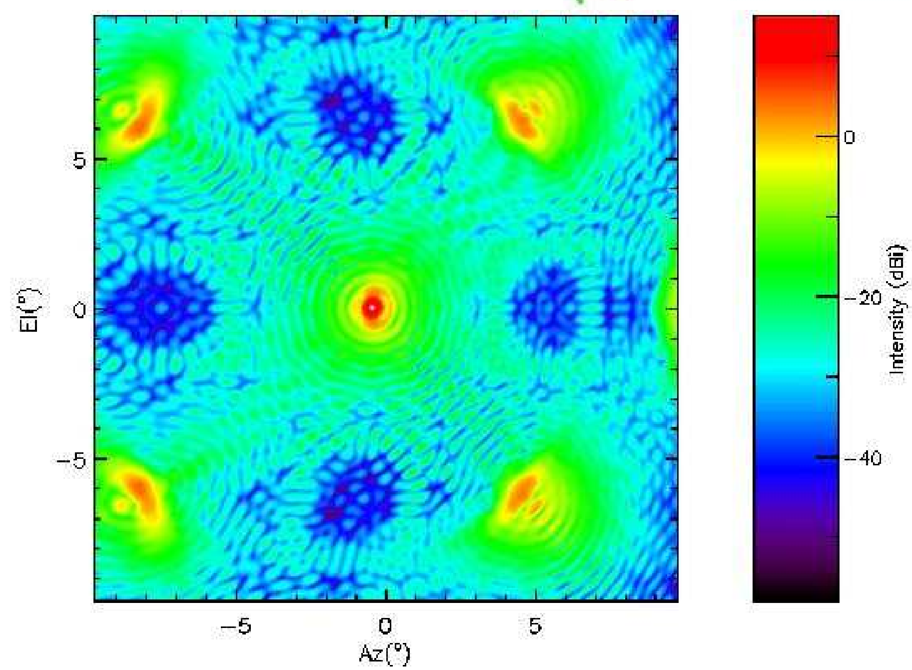
3D CAD by GRASP

Full vector physical analysis (PO) of the performance of the QUBIC Beam Combiner @ 150 GHz

Synthesized beam on sky



PSF



Conclusions

- QUBIC: a novel instrumental concept
  - ✓ Devoted to B-modes quest
  - ✓ Bolometric Interferometry (Fizeau approach)
  - ✓ Synthetized imager or imaging interferometer
  - ✓ Dome-C dedicated site

- Shielding analysis: horn beam pattern sidelobes reduction → Conical shape + flare – absorptive inner surface

- Beam Combiner: optical performances investigation → Synth beam map vs PSF → Low aberrations


Thank you