The QUBIC experiment

the Q U Bolometric Interferometer for Cosmology

Elia Stefano Battistelli
Sapienza, University of Rome

...for the QUBIC collaboration

QUBIC

- *The QUBIC collaboration, 2011, APP, 34, 705-716*
- *Piat et al, 2012, JLTP 167, 872P*
- *Ghbri et al, 2014, JLTP 176, 698*

What is QUBIC?

B-mode				**Q** and
R		**M**illimeter-wave		**U**
Adiation	+	**B**olometric	=	**B**olometric
I		**I**nterferometer		**I**nterferometer for
Nterferometer				**C**osmology

mm interferometric experiments to observe the Cosmic Microwave Background Radiation Polarization

QUBIC collaboration

IT

FR

US

UK

IN

IR

+ NIKHEF, Amsterdam about to join QUBIC

QUBIC

QU Bolometric Interferometer for Cosmology

QUBIC collaboration


IT







FR








A. Ghribi[1] · J. Aumont[4] · E. S. Battistelli[6] · A. Bau[7] · L. Bergé[3] · J-Ph. Bernard[2] · M. Bersanelli[8] · M-A. Bigot-Sazy[1] · G. Bordier[1] E. T. Bunn[12] · F. Cavaliere[8] · P. Chanial[1] · A. Coppolecchia[6] · T. Decourcelle[1] · P. De Bernardis[6] · M. De Petris[6] · A-A. Drilien[3] · Dumoulin[3] · M. C. Falvella[13] · A. Gault[11] · M. Gervasi[7] · M. Giard[2] · M. Gradziel[5] · L. Grandsire[1] · D. Gayer[5] · J-Ch. Hamilton[1] · V. Haynes[9] · Y-G. Hiraut[1] · N. Holtzer[3] · J. Kaplan[1] · A. Korotkov[10] · J. Lande[2] · A. Lowitz[11] · B. Maffei[9] · S. Marnieros[3] · J. Martino[4] · S. Masi[6] · A. Mennella[8] · L. Montier[2] · A. Murphy[5] · M. W. Ng[9] · E. Olivieri[3] · F. Pajot[4] · A. Passerini[7] · F. Piacentini[6] · M. Piat[1] · L. Piccirillo[9] · G. Pisano[9] · D. Prêle[1] · D. Rambaud[2] · O. Rigaut[3] · C. Rosset[1] · M. Salatino[6] · A. Schillaci[6] · S. Scully[5] · C. O'Sullivan[5] · A. Tartari[1] · P. Timbie[11] · G. Tucker[10] · L. Vibert[4] · F. Voisin[1] · B. Watson[9] · M. Zannoni[7]

[1]AstroParticule et Cosmologie, Univ. Paris 7, CNRS · [2]Institut de Recherche en Astrophysique et Planétologie · [3]Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse · [4]Institut d'Astrophysique Spatiale · [5]NUI Maynooth · [6]Università di Roma La Sapienza · [7]Università di Milano Bicocca · [8]Università degli studi Milano · [9]University of Manchester · [10]Brown University · [11]Universityof Wisconsin · [12]University of Richmond · [13]Italian Space Agency

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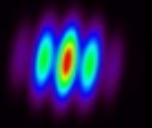

QUBIC

QU Bolometric Interferometer for Cosmology

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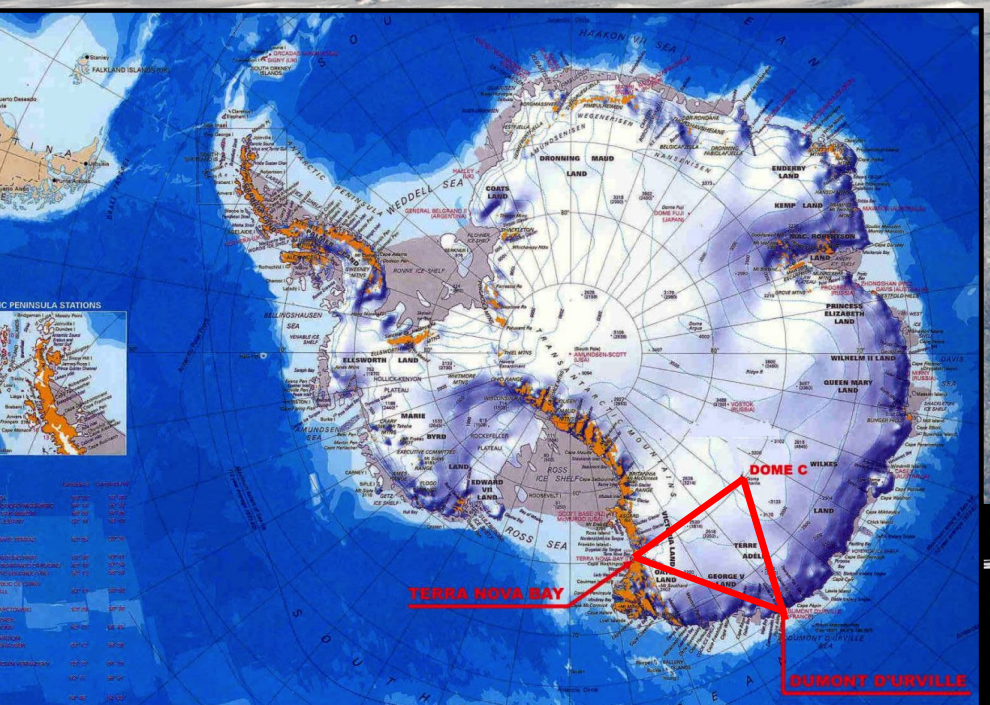
Concordia Station: Dome C



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

QUBIC Site: Dome C

Great Base

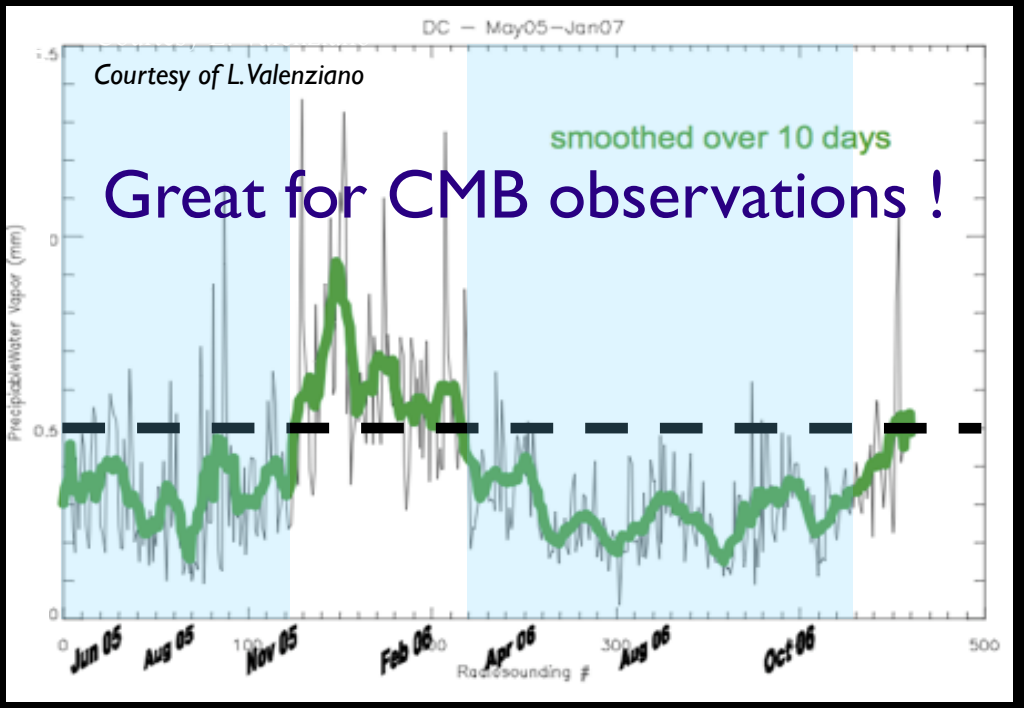
Great landscape

Great Infrastructures

Healthy weather

QUBIC Site: Dome C

Great Base



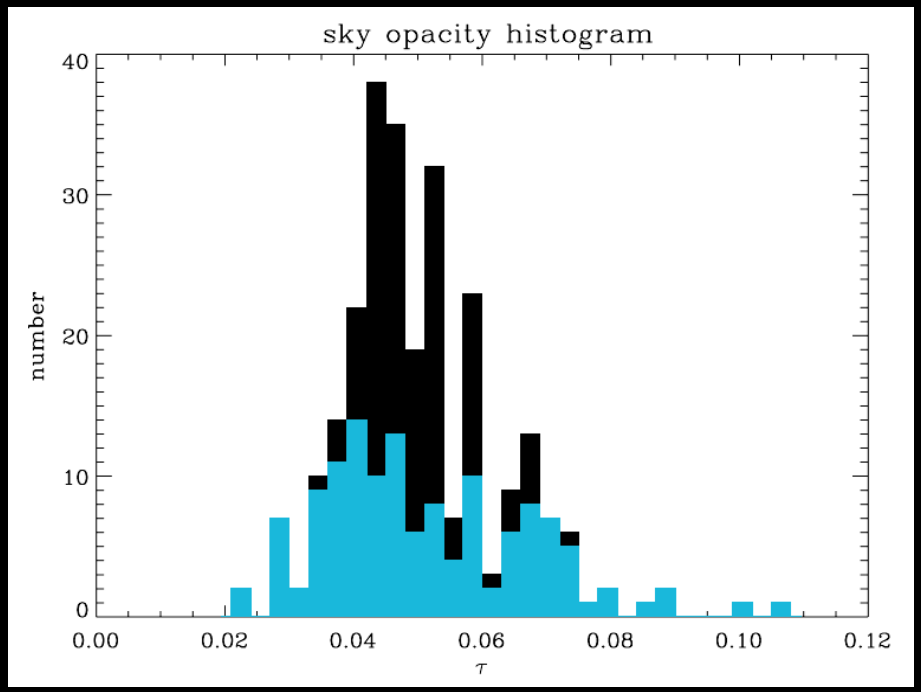
Great Infrastructures

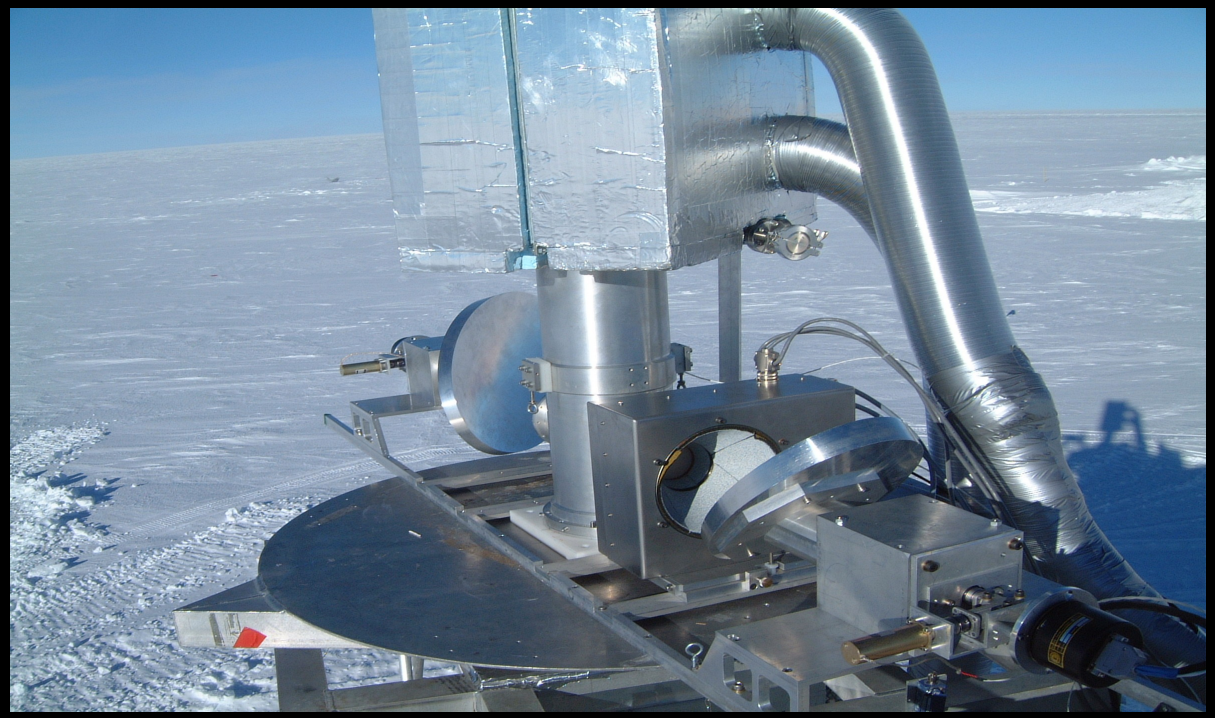
Healthy weather

BRAIN: site testing

- *Spinelli,, et al., MNRAS, 414, 3272S, 2011*
- *E. Battistelli et al., MNRAS 423, 1293, 2012*

2009-2010 campaign was dedicated to mm atmospheric emission and polarization: this was done at 150GHz





$$\langle \tau \rangle = 0.050 \pm 0.003 \pm 0.011$$

CIRCULAR POLARIZATION < 0.19 %

LINEAR POLARIZATION < 0.11 %

We inferred <PWV> lower than 0.6mm during summer but this is a direct 150GHz measurement

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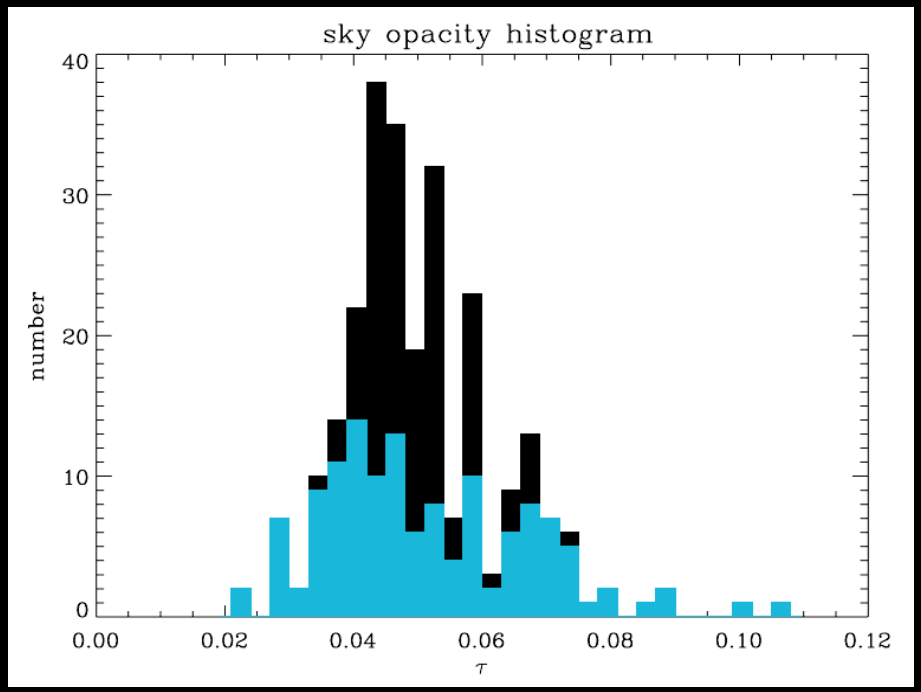
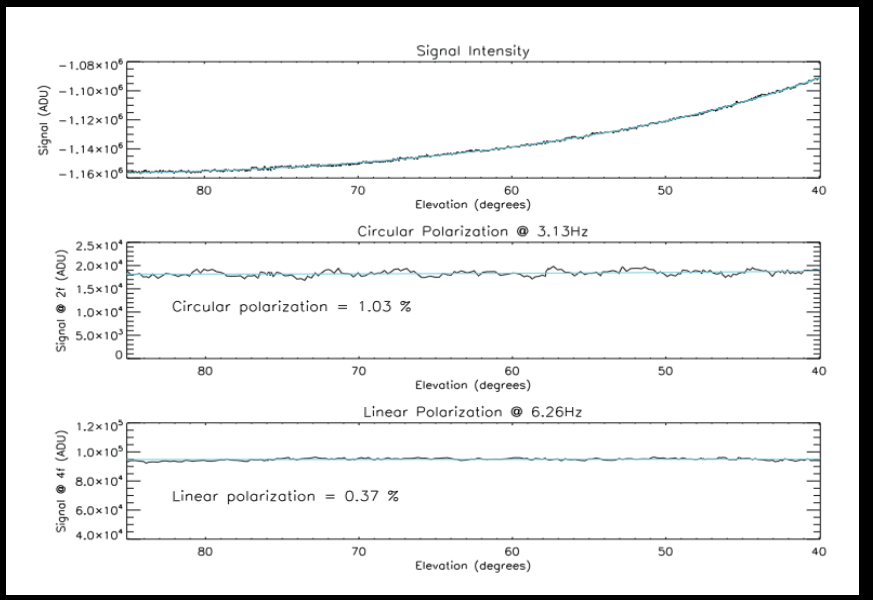




We set upper limits on both circular and linear polarization from atmosphere

$$\langle \tau \rangle = 0.050 \pm 0.003 \pm 0.011$$

CIRCULAR POLARIZATION < 0.19 %

LINEAR POLARIZATION < 0.11 %

We inferred <PWV> lower than 0.6mm during summer but this is a direct 150GHz measurement

Possible instruments

- Imagers with bolometers (thermal):
  - No doubt they are nice detectors for CMB:
    - wide band
    - low noise

Good sensitivity

- Interferometers (coherent):
  - Long history in CMB
    - CMB anisotropies in the late 90s (CAT, VSA, CBI…
    - CMB polarization 1st detection (DASI, CBI)
  - Clean systematics:
    - No telescope (lower ground-pickup & cross-polarization)
    - Angular resolution set by receivers geometry (well known)
  - Technology used so far
    - Antennas + HEMTs : higher noise wrt bolometers

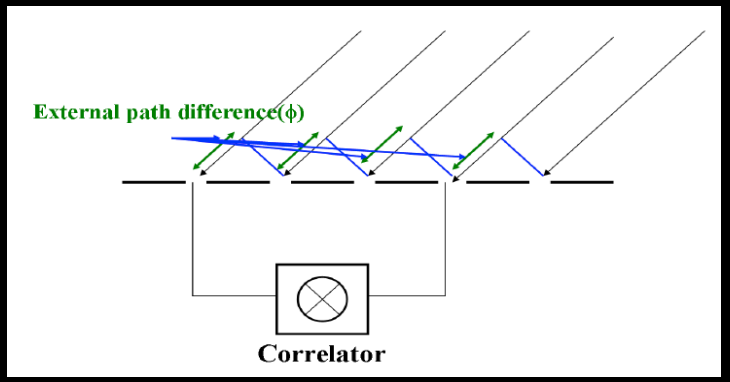
Good control of systematics

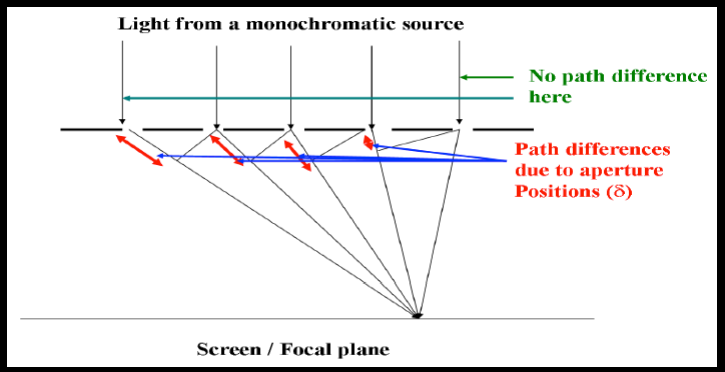
- Can these two nice devices be combined ?
  - Bolometric Interferometry !

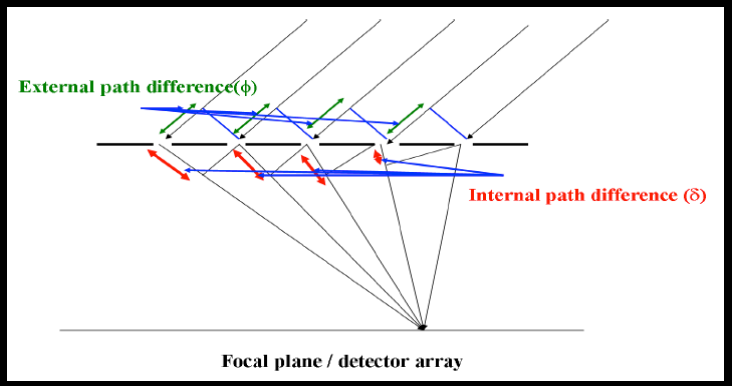
Both

Possible configuration

- In an interferometer, radiation is selected by diffractive apertures and then recombined
- QUBIC is an adding interferometer: we use the Fizeau approach in which all the outputs are summed (linear combination) into the detector array. Better when there are several apertures.
- Phase difference is present both before and after the incoming antennas: External phase difference gives the relation visibility FT sky-image…similarly does the internal phase difference but FT^{-1}
- Thus a Fizeau combination enables imaging in an interferometer except that images are modulated by synthesized beam produced by interference pattern
- Horns act as diffractive apertures and make a "spatial filtering": QUIBC is an imager that accept only a sub-set of modes





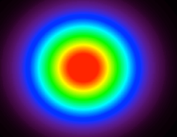


QUBIC in a nutshell

- Bolometric interferometer: adding interferometer (synthetic imager) to use the sensitivity of bolometers and the systematic control of interferometers
- To be installed in Dome C: probably the best place on earth (like Carlsberg beer)
- ~1.5% of the cleanest sky mapped multifrequency with HWP polarization capability
- Angular resolution: a little difficult for an interferometer…let's say 0.5°
- 1st module December 2016 with 2000 TES at 150GHz and 220GHz: goal r<0.05 at 90% C.L.: anticipated sensitivity:
  -3.7uK/arcmin @ 150GHz
  -9.8uK/arcmin @ 220GHz
- Extended: 6 modules, at 90, 150, 220GHz possibly with KID detectors: goal r<0.01 at 90% C.L….it will require a deep rethinking of Dome C

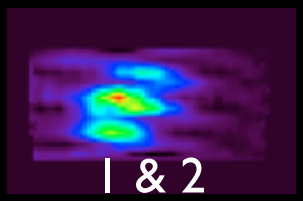
QUBIC design

fringes successfuly observed in 2009 with MBI-4 [Timbie et al. 2006]

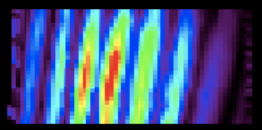


1 horn open

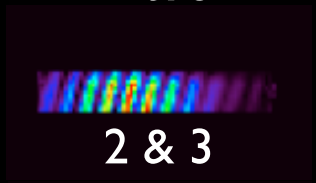
MBI-4 data
2009 campaign
(PBO- Wisc.)



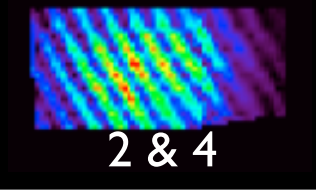
1 & 2



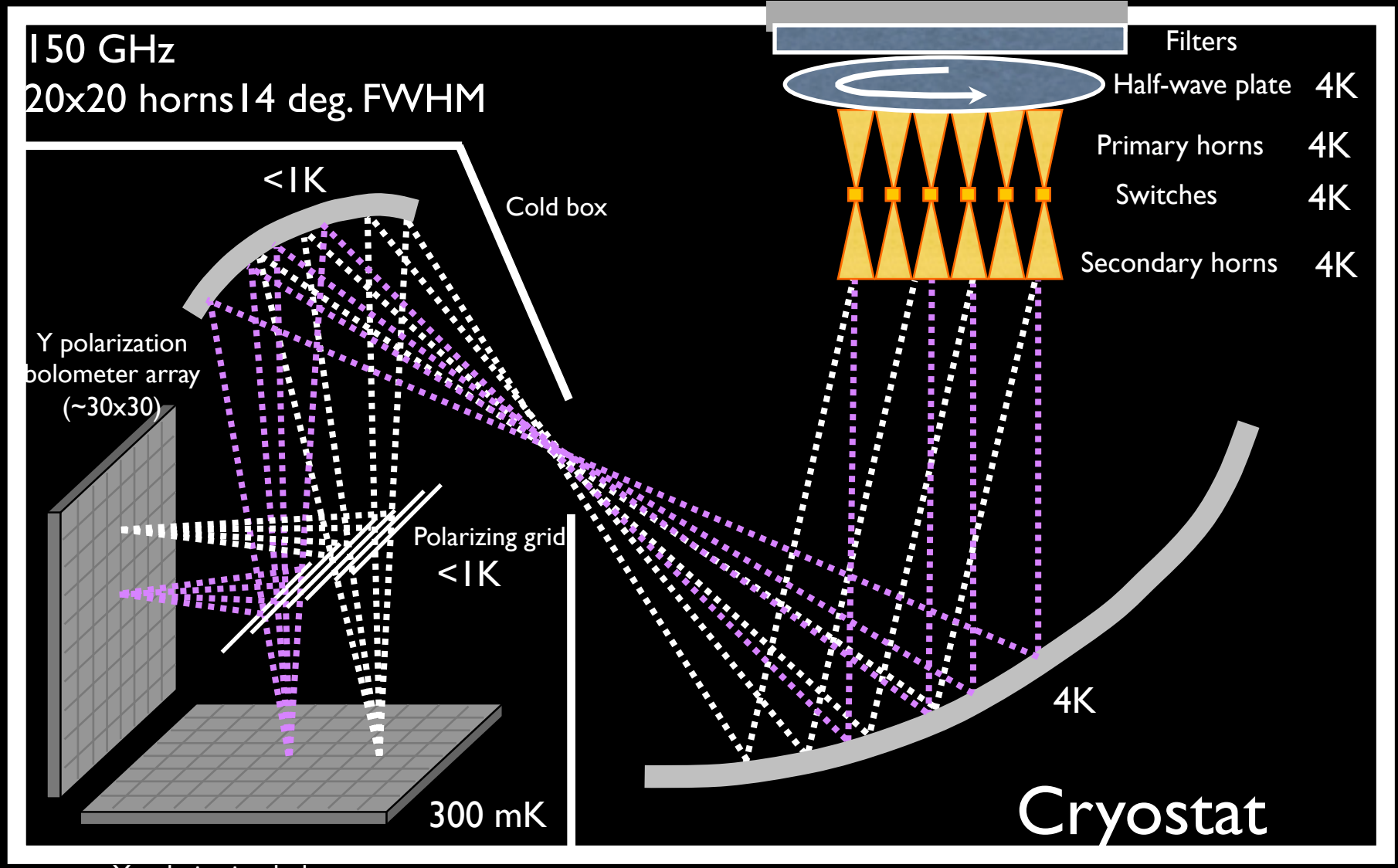
1 & 3



2 & 3



2 & 4



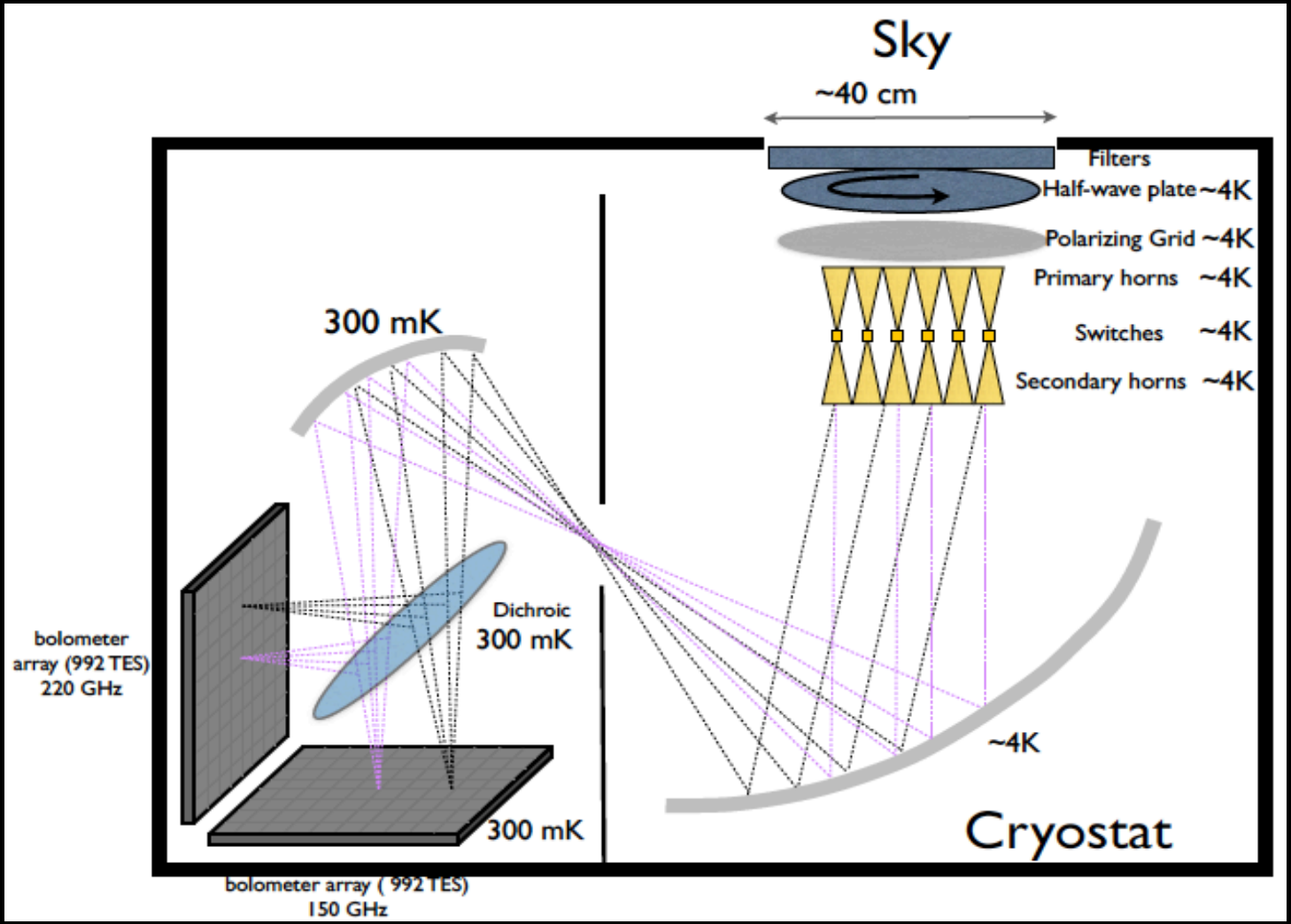
QUBIC
QU Bolometric Interferometer for Cosmology

Dual Band QUBIC (150/220 GHz in the first module)

- B2B horns are:
  -single moded at 150GHz
  -multi- (few-) moded at 220GHz
  they are diffractive apertures that make spatial filtering i.e. the entrance pupil is a square array of gaussian-illuminated apertures

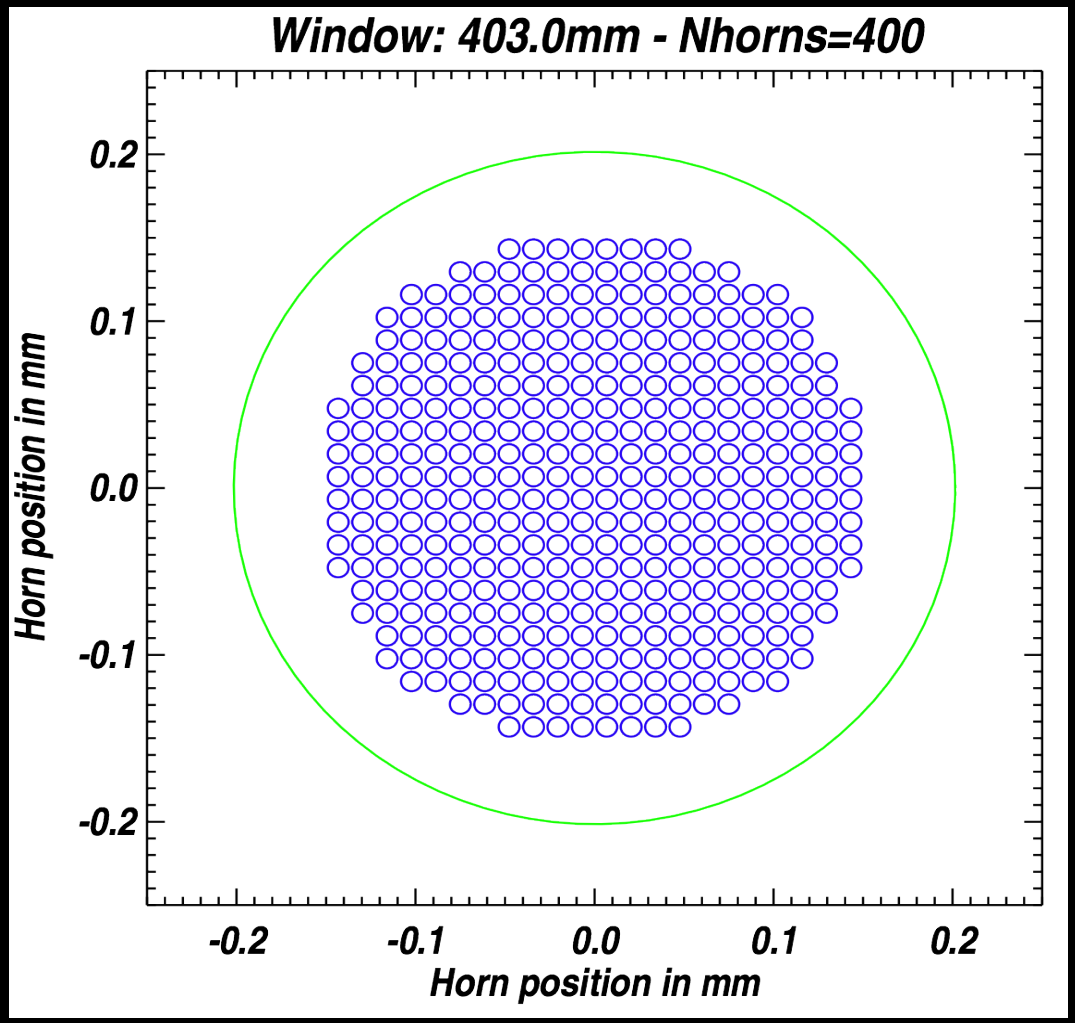
- The beam combiner alone can be used as a telescope (uniformly illuminated pupil) with N~FOV/(λ/D) independent Airy spots

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



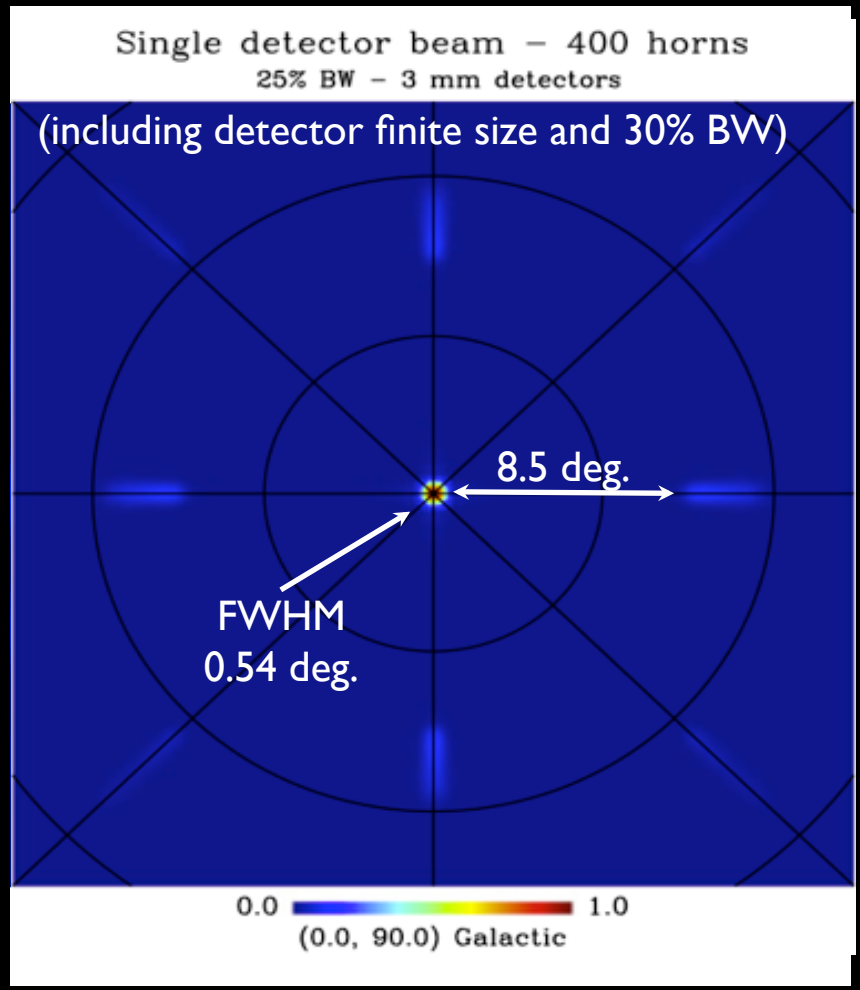
B.I. = Synthesized imager

Primary horns array



20x20 horns 14 deg. FWHM, D=1.2 cm

Synthesized beam



Synthesized beam used to scan the sky as with an imager

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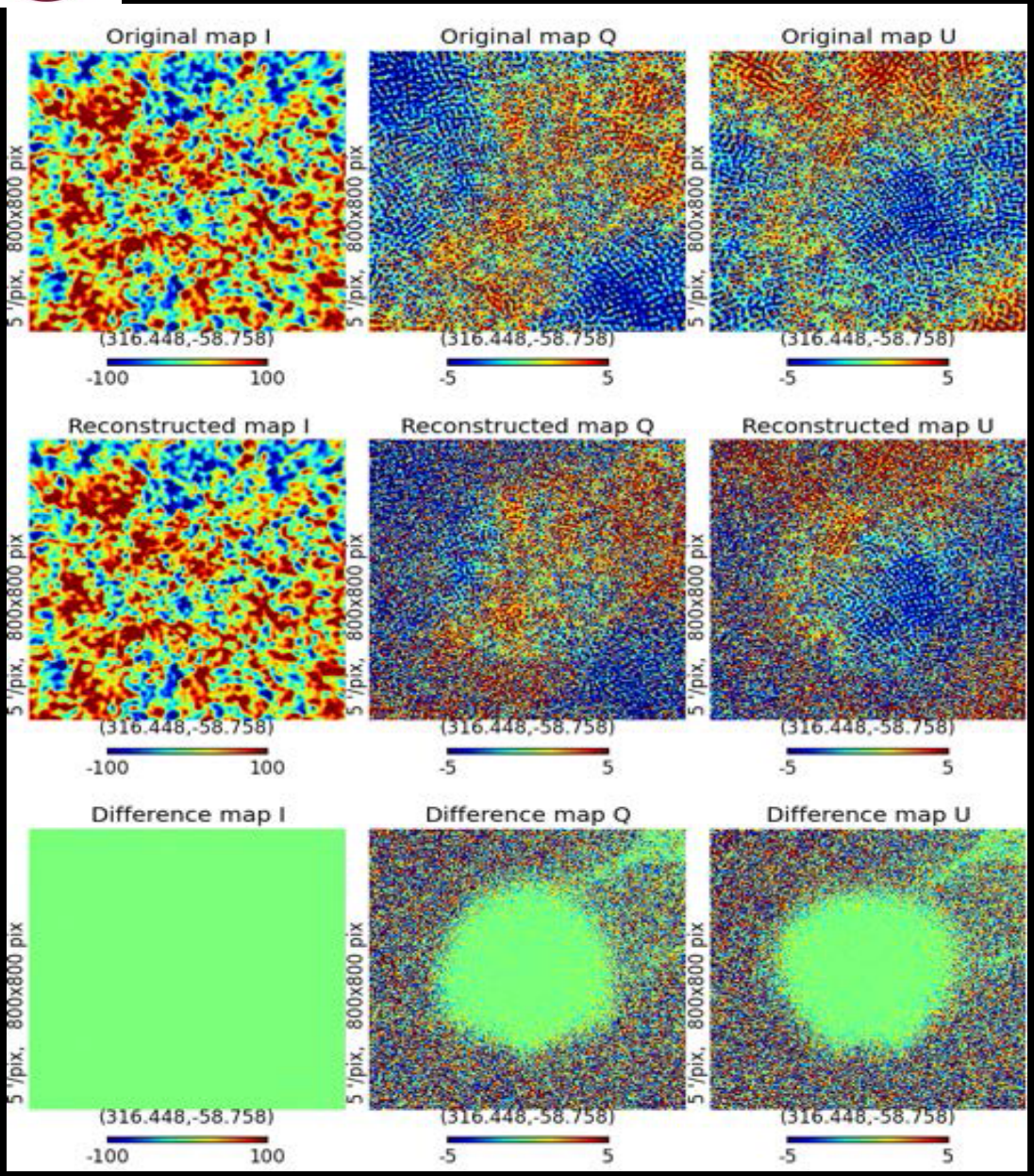
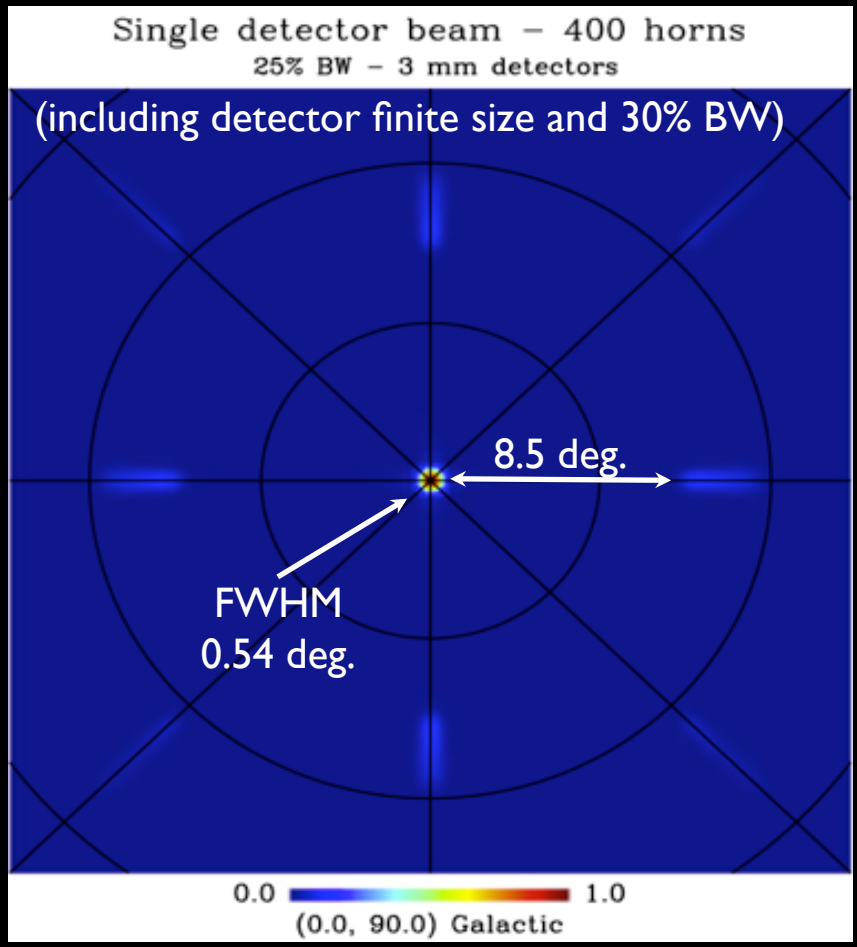


Synthesized beam



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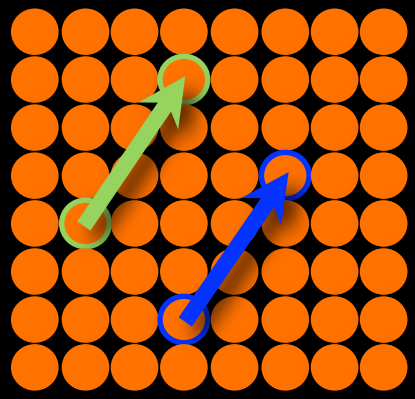
Acknowledgments to P. Chanial

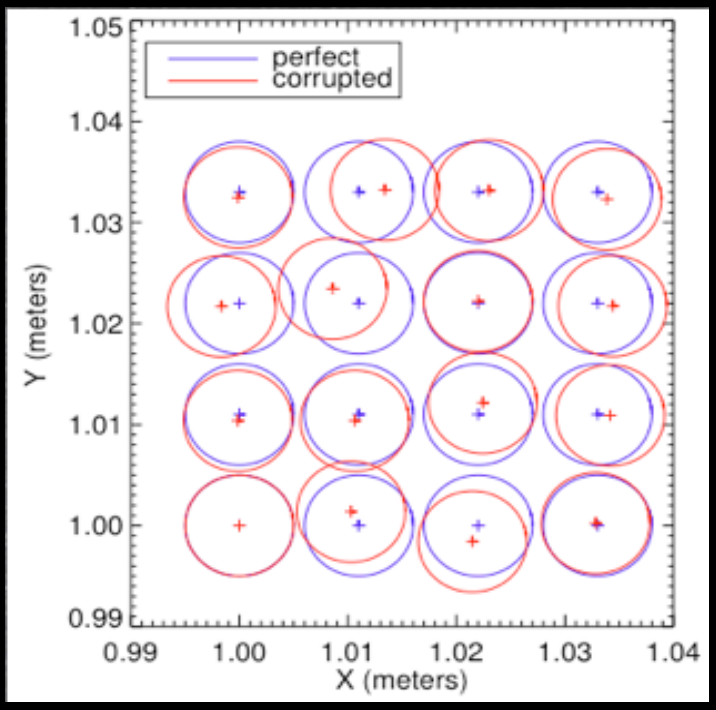
Systematics: Self-Calibration

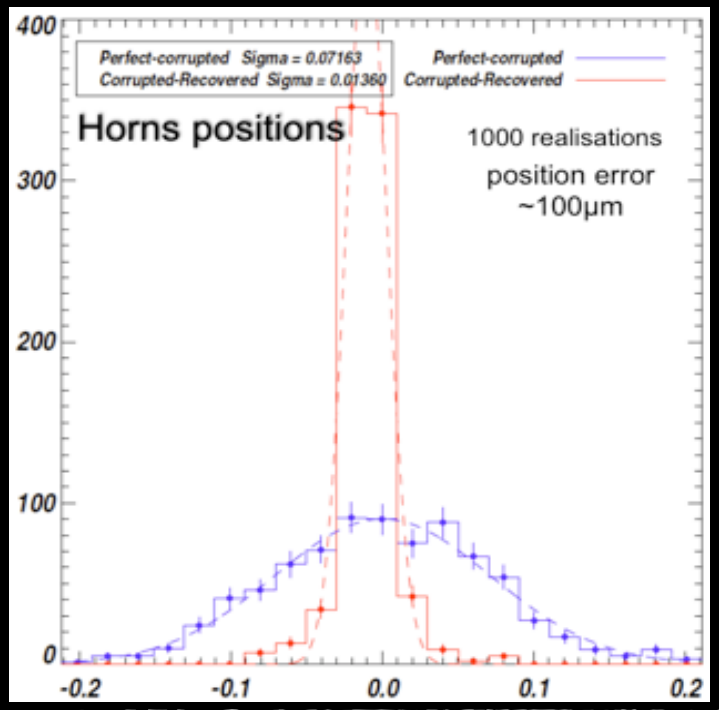
- BI relies on the accurate knowledge of your instrument including the departure from idealities
- A unique possibility to do that, and to handle systematic errors, is the self-calibration
- Use horn array redundancy to calibrate systematics
  - In a perfect instrument redundant baselines should see the same signal
  - Differences due to systematics
  - Allow to fit systematics with an external source on the field



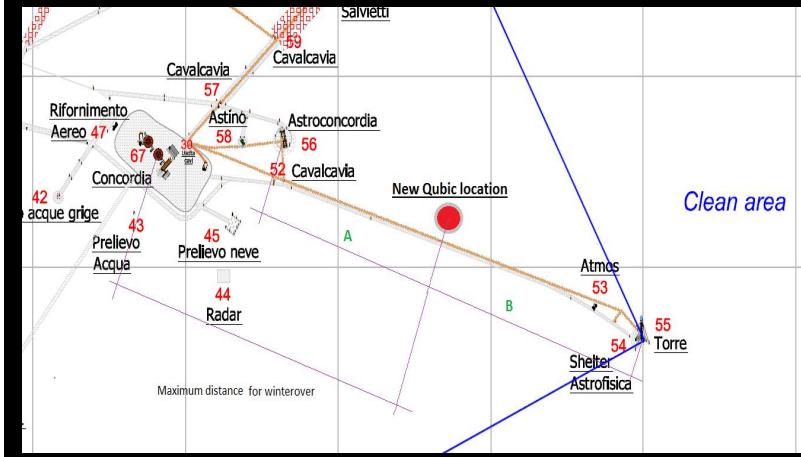
Redundant baselines : same Fourier Mode

Example: exact horns locations (figure exaggerated !!)





An active source will be used disentangle different systematics and departure from idealities



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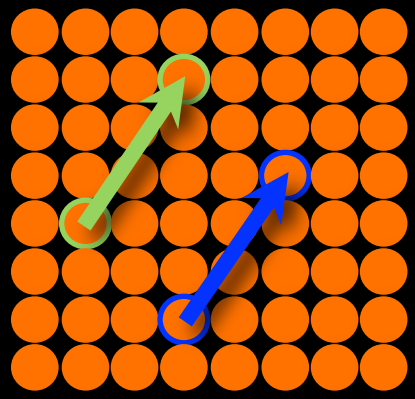

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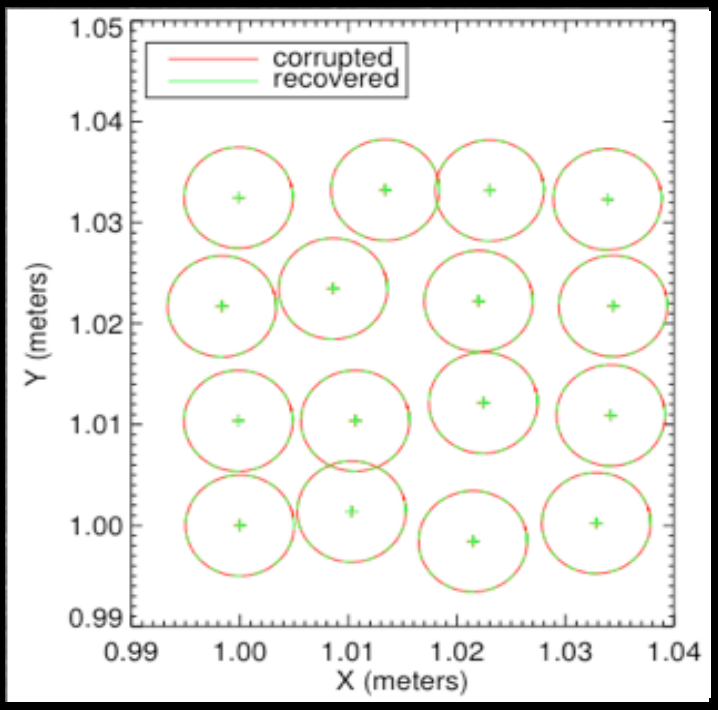
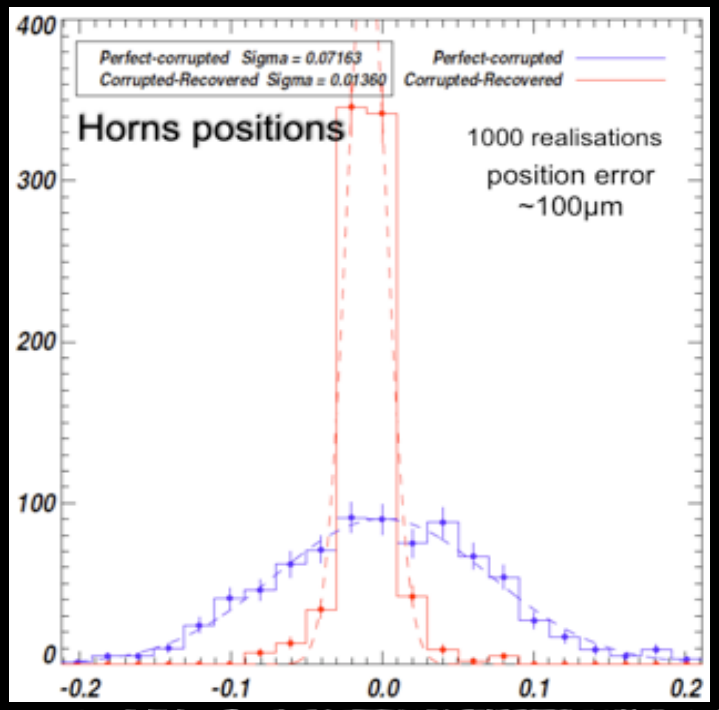
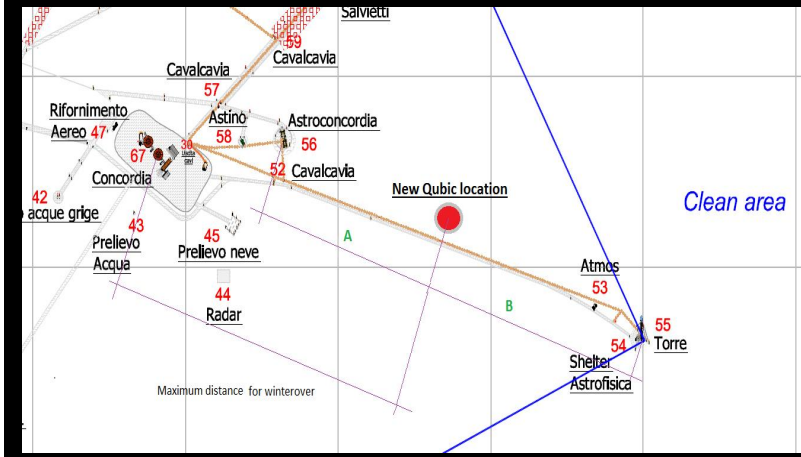
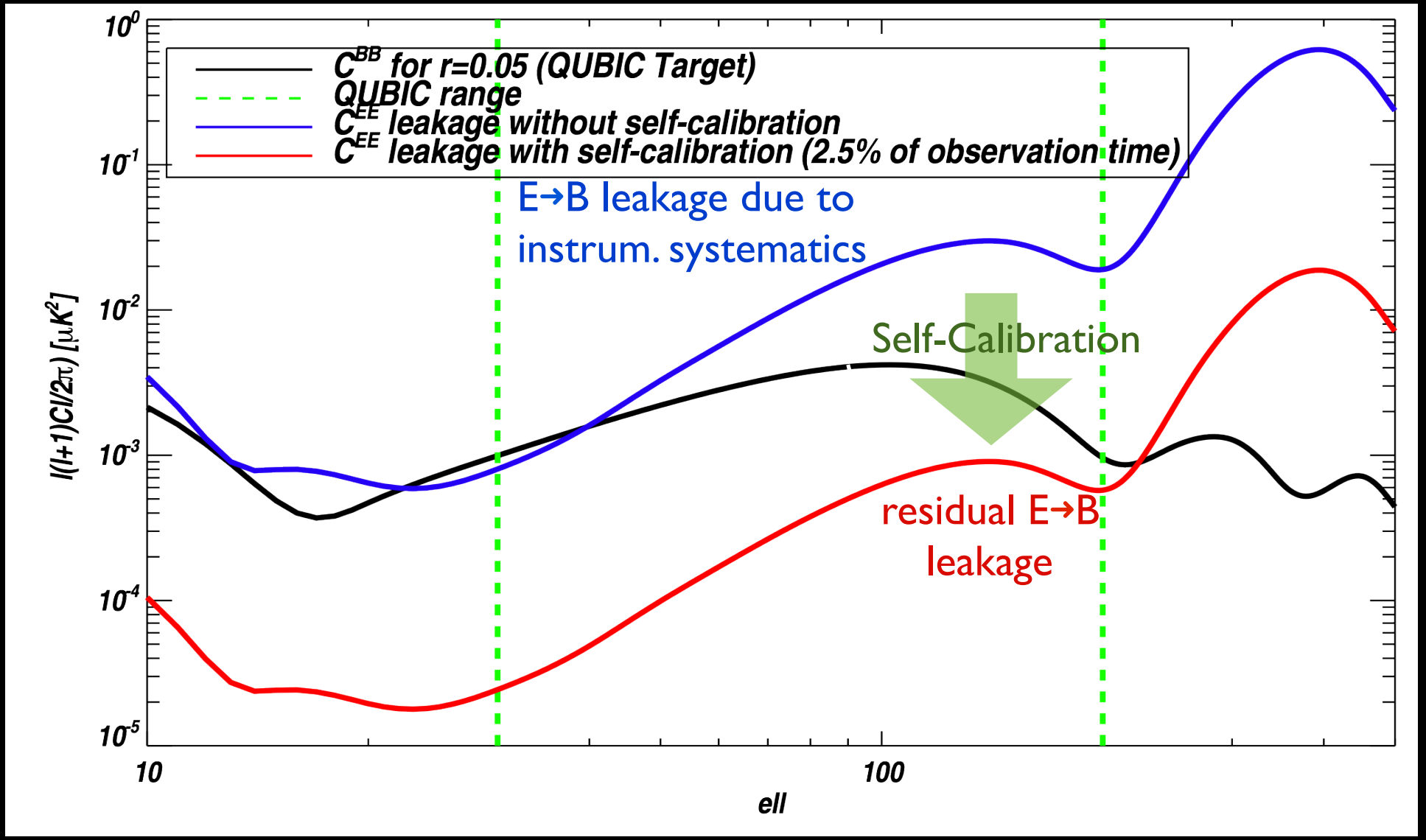




An active source will be used disentangle different systematics and departure from idealities



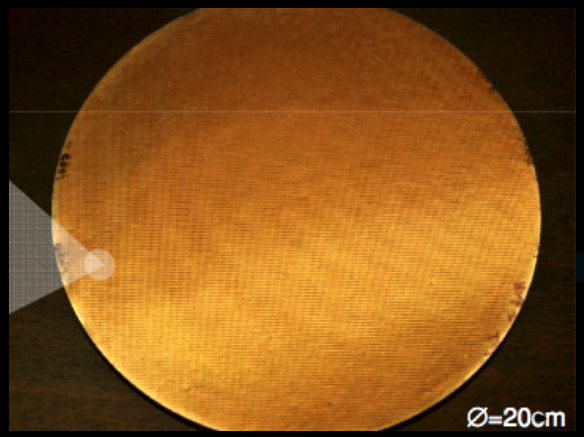
Self-Calibration results



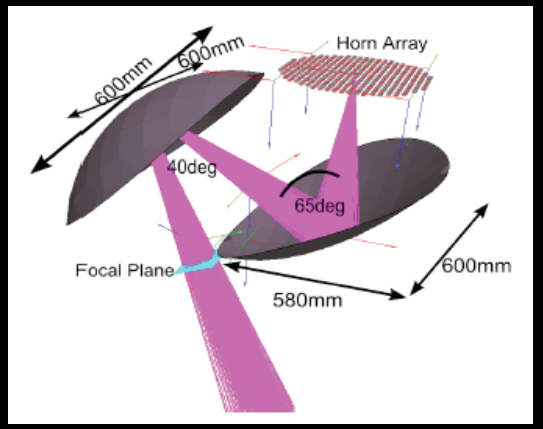
[Bigot-Sazy et al., A&A 2012, arXiv:1209.4905]

THE INSTRUMENT

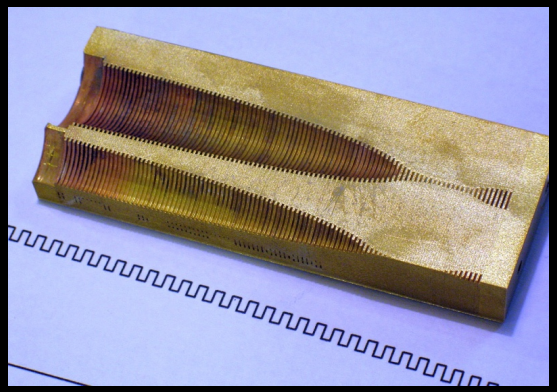
Dielectrically embedded mesh HWP
Cardiff, G. Pisano et al. 2012

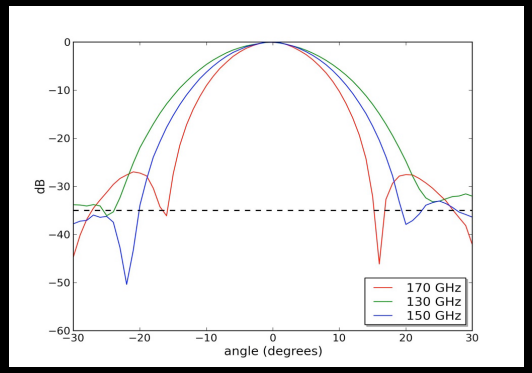


Off-Axis Gregorian System, 300mm equivalent focal length, 0.5m mirrors, Low aberrations (Maynhoot, Rome)

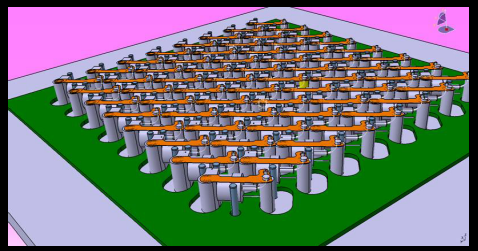


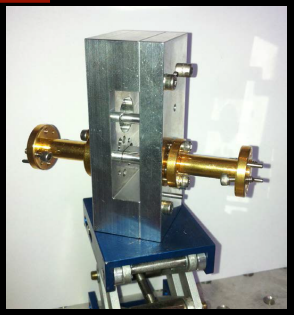
400 primary horns, aluminum platelet FWHM = 14°
Milano Courtesy of F. Cavaliere





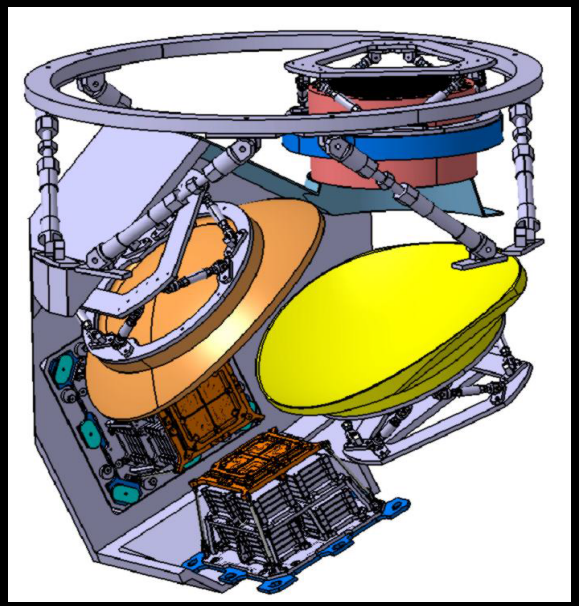
Electro-magnetic switches mainly used for self-calibration
Milano Bibocca, APC, Paris

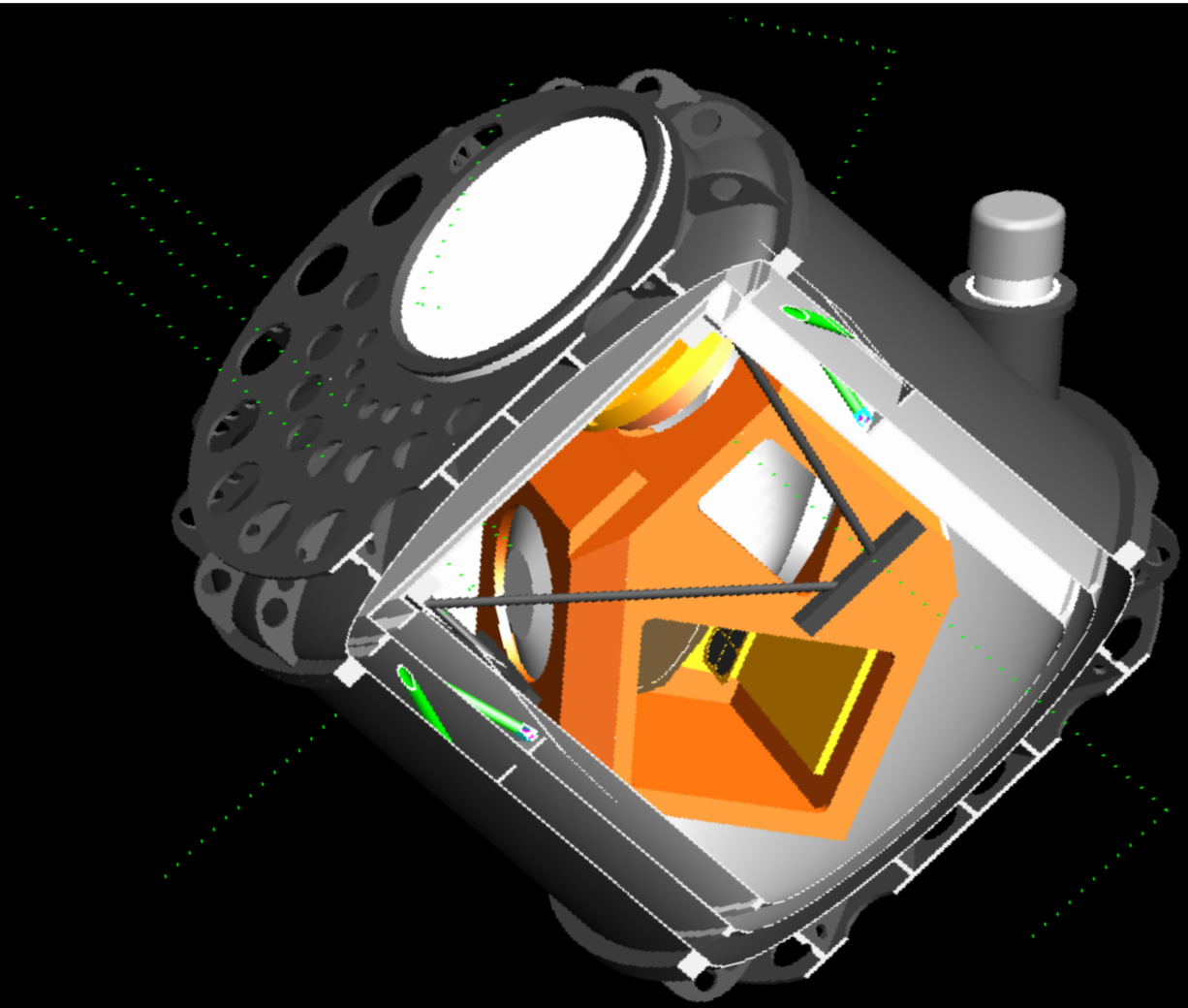




THE INSTRUMENT

Subsystem	Temperature
HWP	3 K
Polarizing grid	3 K
Horn Arrays	3 K
Primary mirror	1 K
Secondary Mirror	1 K
Detector arrays	0.3 K
Read out electronics	1 K and 40 K





Dry cryostat with G10 truss
Sapienza (Schillaci-Masi)

Acknowledgments to C. Chaperon

THE INSTRUMENT

-TES + SQUIDs + SiGe ASIC Mux

-2 arrays of 992 NbSi TES

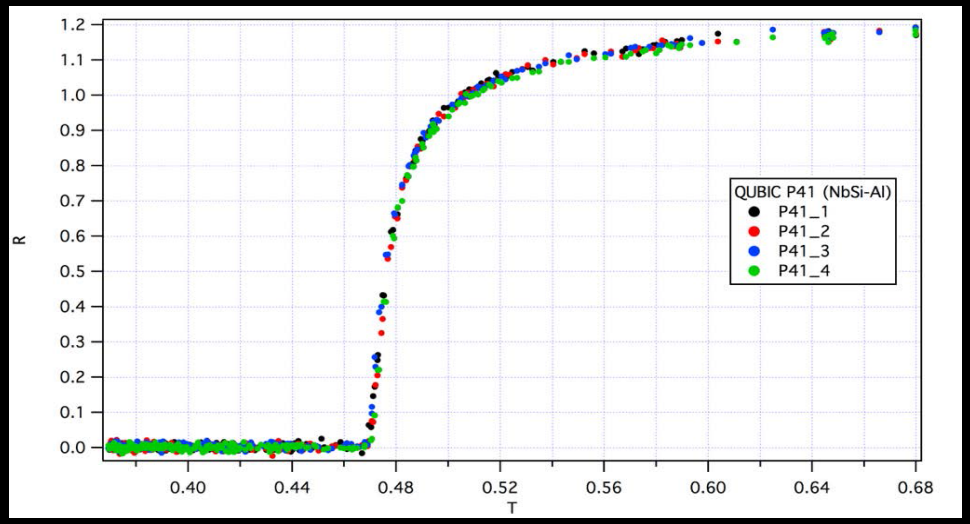
-Capacity coupling-Time Domain Multiplexing

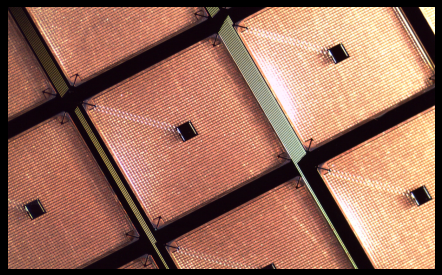
-Bias reversal AC SQ1 bias

-The current bias steps through the rows for a first multiplexing stage and a cryogenic amplifier steps through the columns for a second multiplexing stage

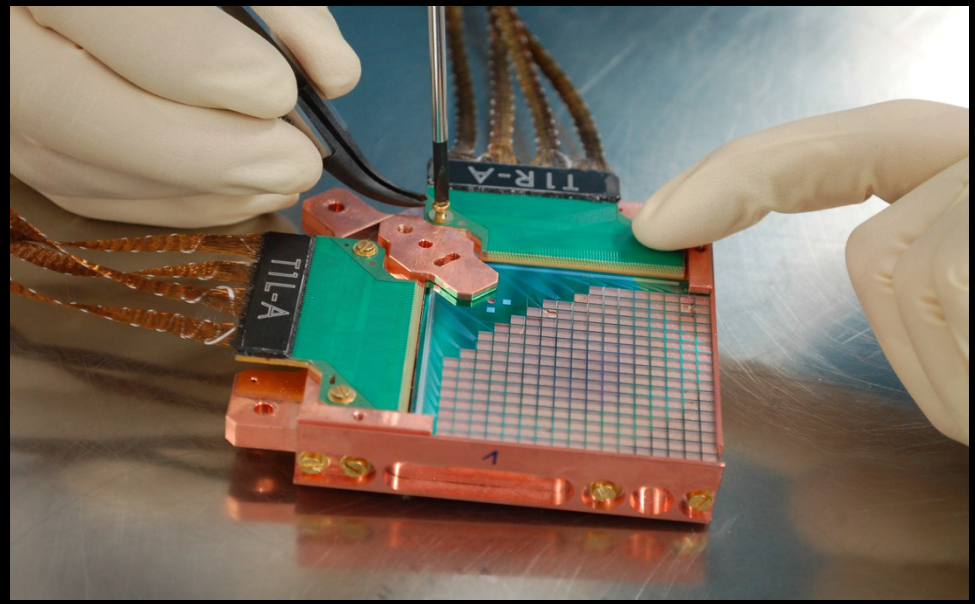
-This is done by the ASIC

-Multiplexing factor 128/1 in a 2D configuration





M. Piat – APC, Marnieros - CNSNM



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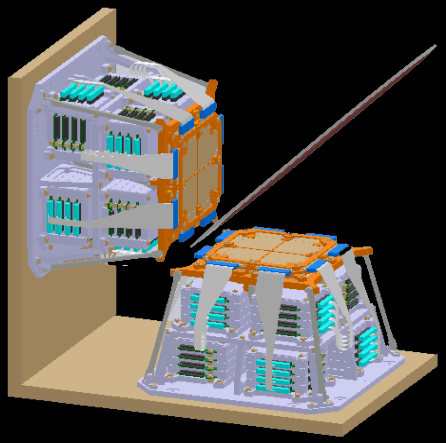
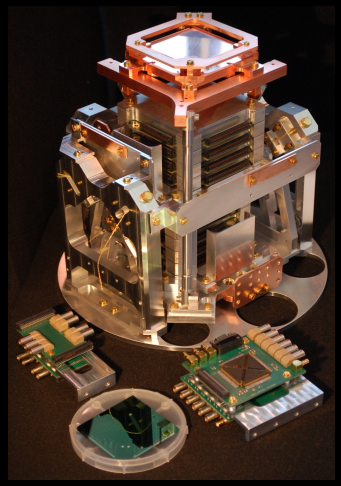
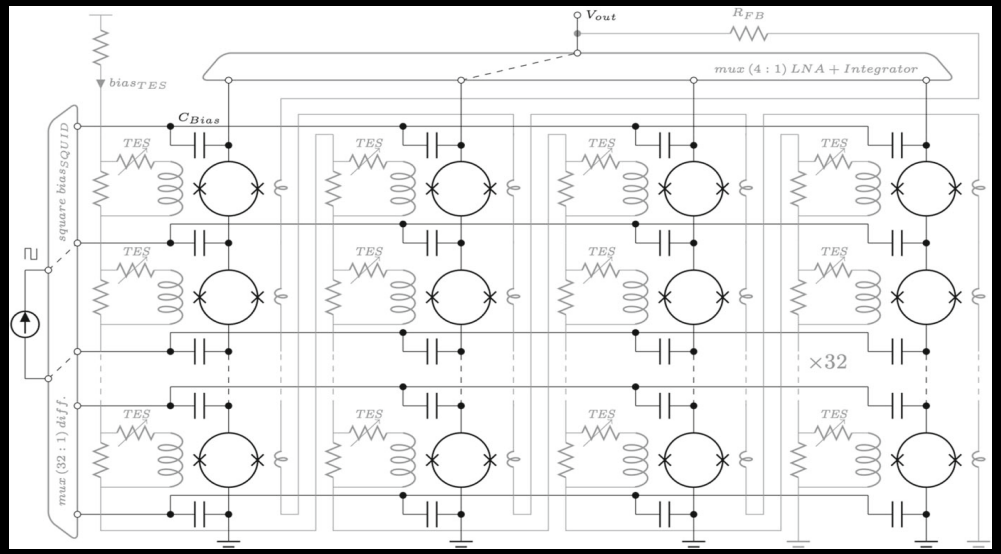




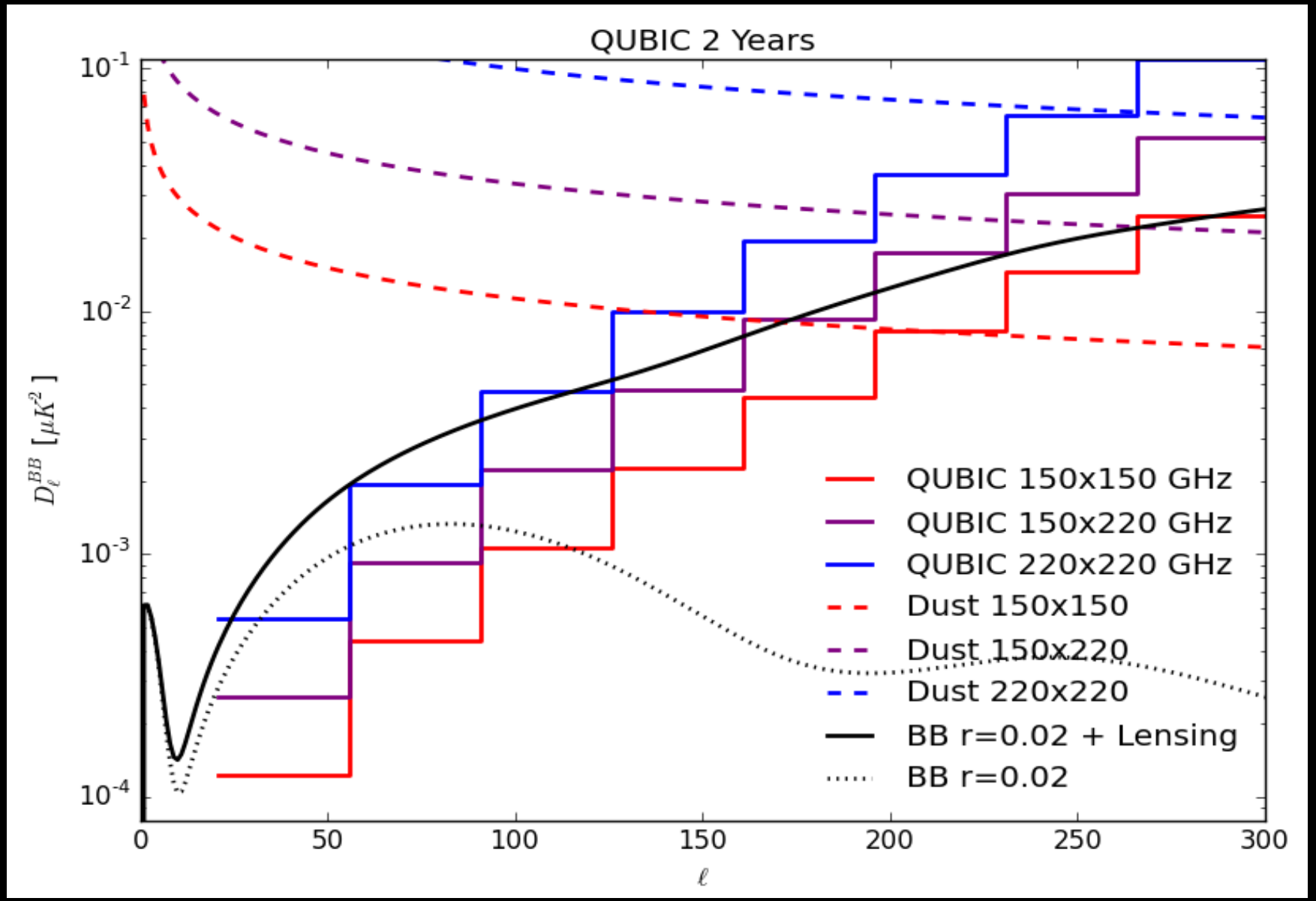


M. Piat – APC, Prele - APC

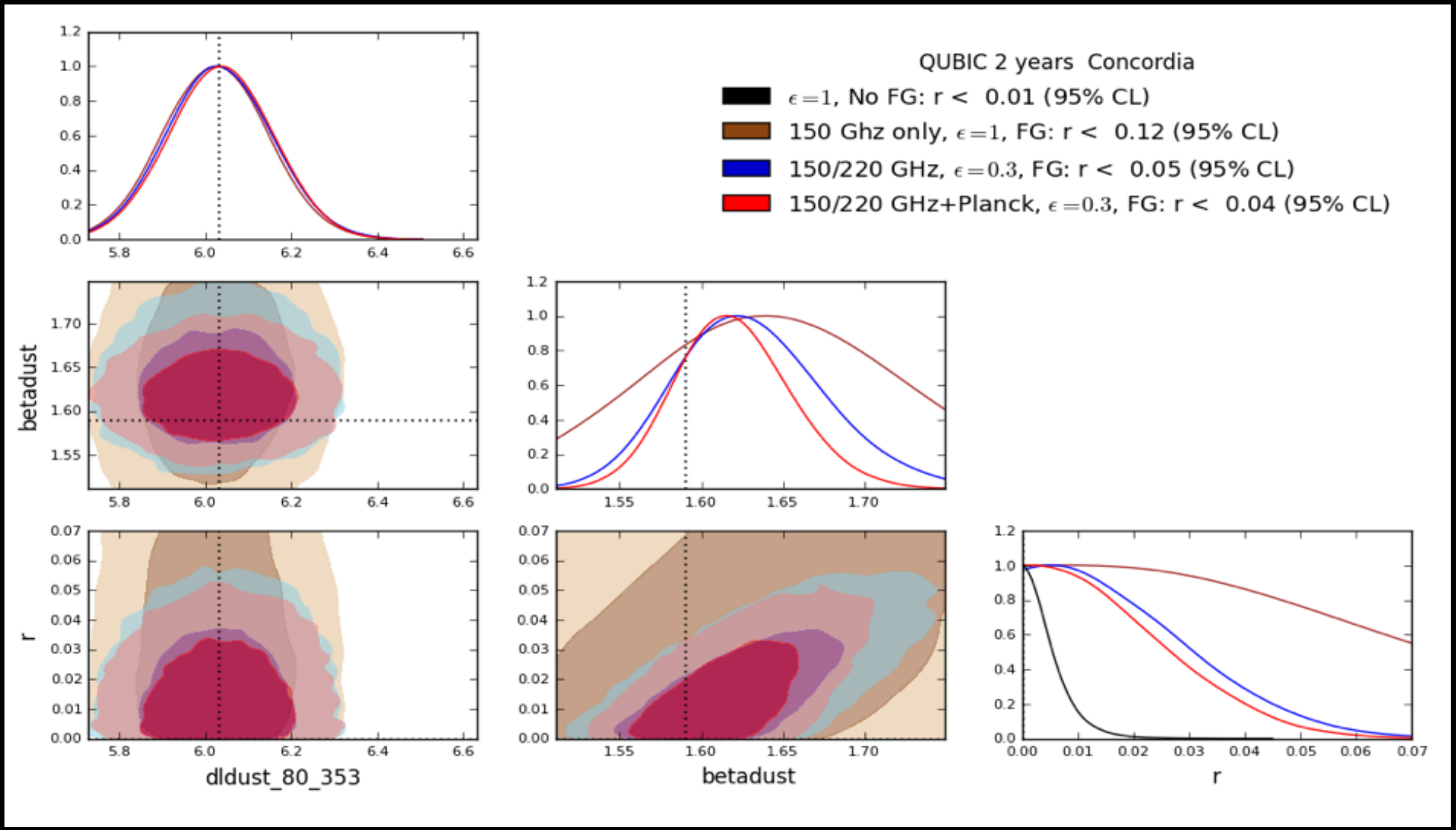
QUBIC

QU Bolometric Interferometer for Cosmology

Forecast

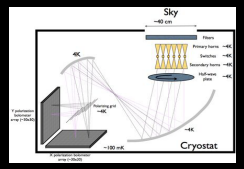

QUBIC 2 Years
10^{-1}
10^{-2}
10^{-3}
10^{-4}
D_ℓ^{BB} [μK^2]
0
50
100
150
200
250
300
ℓ
QUBIC 150x150 GHz
QUBIC 150x220 GHz
QUBIC 220x220 GHz
Dust 150x150
Dust 150x220
Dust 220x220
BB r=0.02 + Lensing
BB r=0.02

Forecast

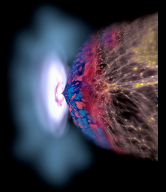

QUBIC 2 years Concordia
$\epsilon=1$, No FG: r < 0.01 (95% CL)
150 Ghz only, $\epsilon=1$, FG: r < 0.12 (95% CL)
150/220 GHz, $\epsilon=0.3$, FG: r < 0.05 (95% CL)
150/220 GHz+Planck, $\epsilon=0.3$, FG: r < 0.04 (95% CL)
betadust
r
dldust_80_353
betadust
r

Summary

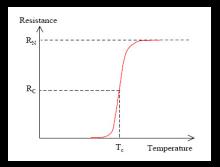
- QUBIC is a novel instrumental concept



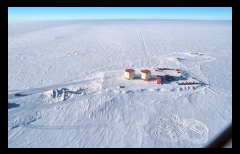
★ Bolometric Interferometer optimized to handle systematics: QUBIC is a synthesized imager (or an imaging interferometer) observing a selected range of spatial frequencies that can be accurately calibrated



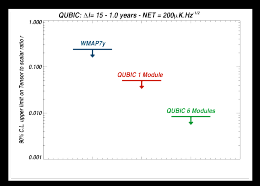
★ Dedicated to CMB polarimetry and inflationary physics



★ High sensitivity with ~2000 TES bolometers



★ Located at Dome C, Antarctica



★ <u>Target :</u>

- First module (150/220 GHz): r < 0.05 at 90% C.L. (first light late 2016)
- Six modules (90, 150, 220 GHz) : r < 0.01 at 90% C.L.