QUBIC
a Q&U Bolometric Interferometer for Cosmology

QUBIC: Q & U Bolometric Interferometer for Cosmology

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CONICET

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Facultad de Ciencias Astronómicas y Geofísicas
UNIVERSIDAD NACIONAL DE LA PLATA

CONICET
Consejo Nacional de Investigaciones Científicas y Técnicas

Outline

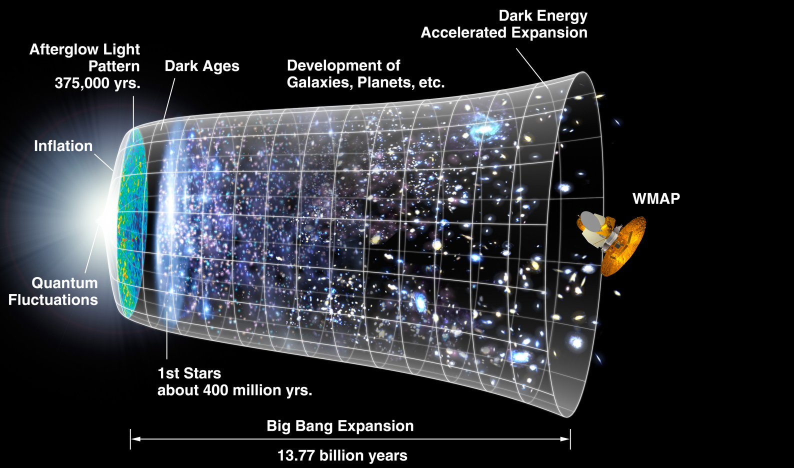
What are the primordial B modes polarization?

The QUBIC instrument

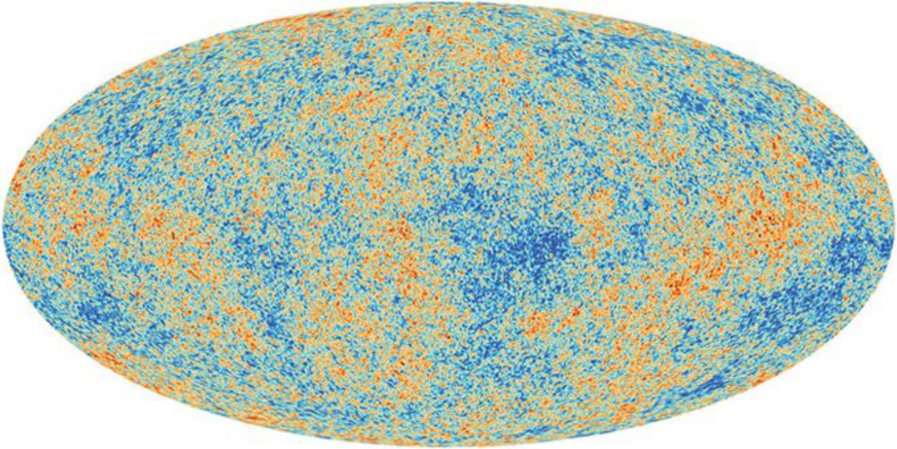
The Alto Chorrillos site

Spectro-imaging with QUBIC

Current Status


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years
NASA/WMAP Science Team

Relic radiation from the Big Bang: CMB



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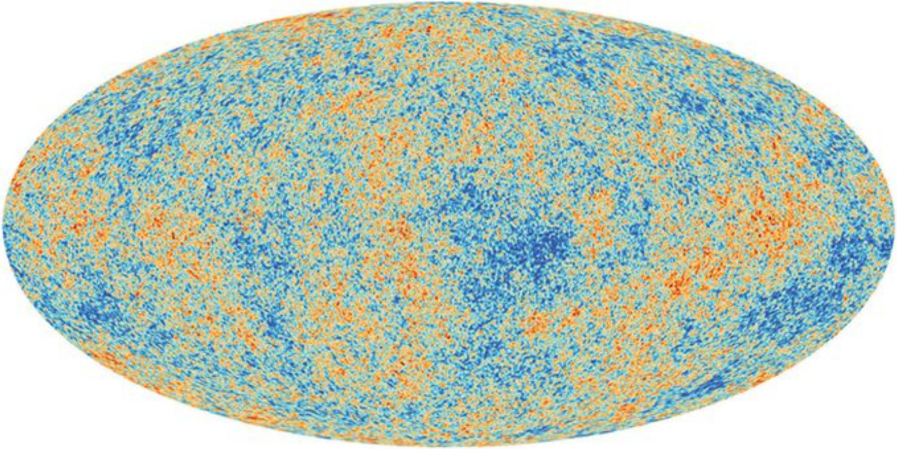

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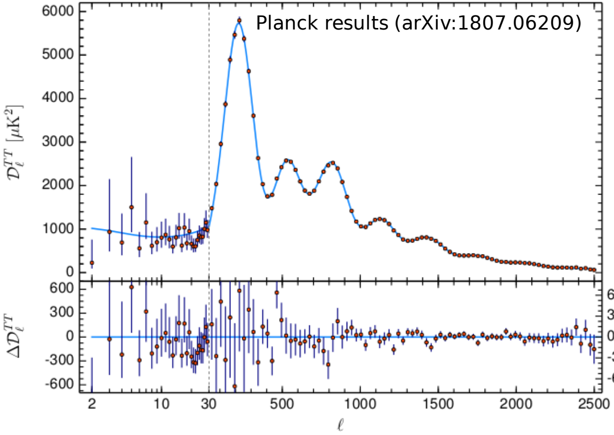

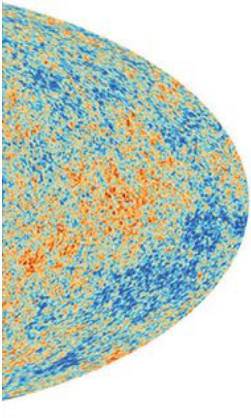

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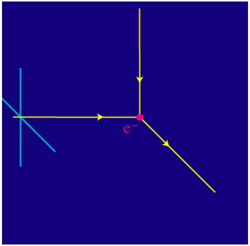
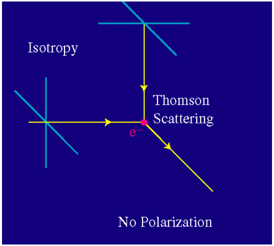
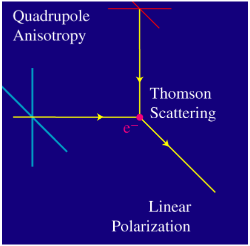
Linear Polarization (produced by Thomson scattering) Credit: W. Hu



Thomson scattering



No polarization
if isotropy



Net polarization
if anisotropy

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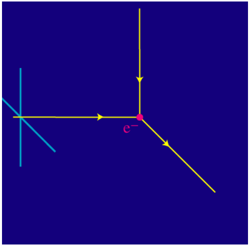

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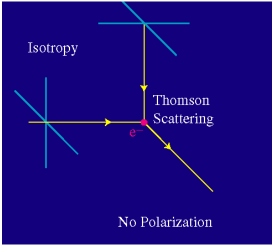

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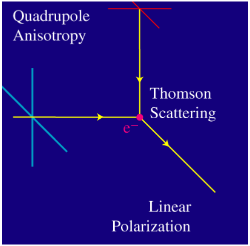

Net polarization if anisotropy

- Predicted in 1968, and confirmed in 2002 by DASI.

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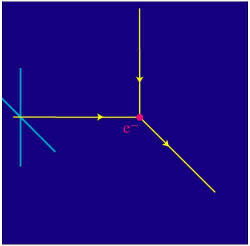

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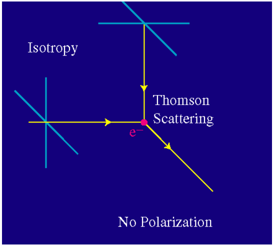

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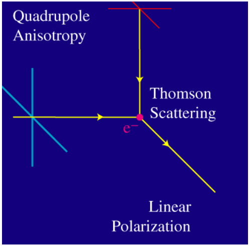

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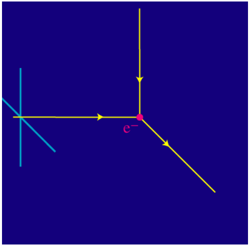

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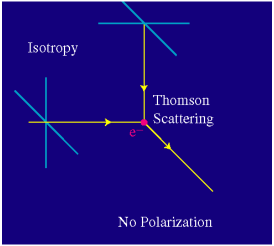

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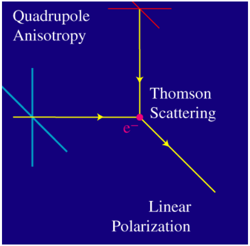

Net polarization if anisotropy

- Predicted in 1968, and confirmed in 2002 by DASI.
- Density (scalar) perturbations are responsable for most of the CMB anisotropy and polarization.
- Also a small contribution from tensor perturbations $\rightarrow$ method to disentangle the fraction of polarization originated in gravitational waves.

Stokes parameters — E and B modes

Polarization is typically described in terms of Stokes parameters Q and U, that can be expanded in spherical harmonics with spin 2:

$$(Q \pm iU) = \sum_{lm} a_{lm}^{(\pm 2)} Y_{lm}^{(\pm 2)} \ . \tag{1}$$

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Alternatively, E and B modes are defined through the linear combinations

$$\begin{aligned} a_{lm}^{E} &= -(a_{lm}^{(+2)} + a_{lm}^{(-2)})/2 \\ a_{lm}^{B} &= -(a_{lm}^{(+2)} - a_{lm}^{(-2)})/2i \ . \end{aligned} \tag{2}$$

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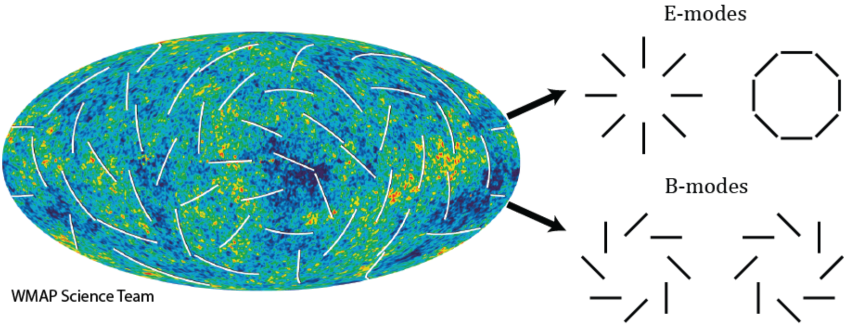
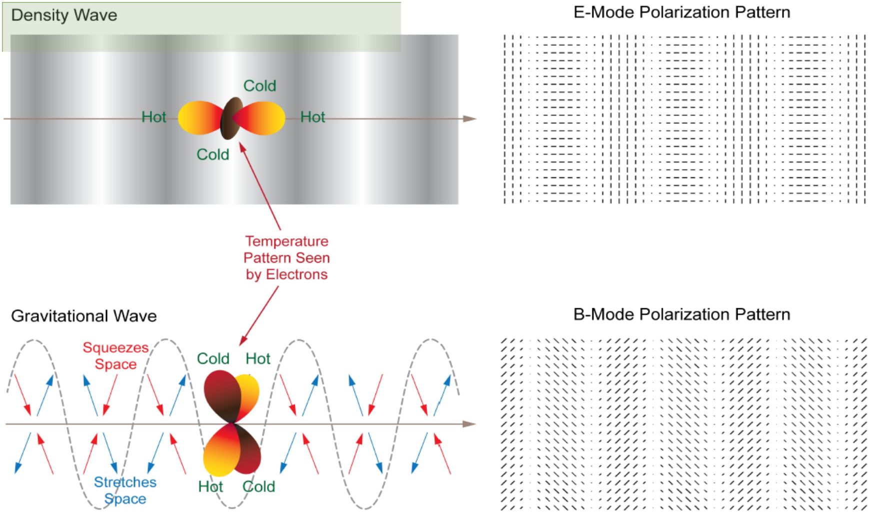
These modes are non-local, and describe a polarization pattern around each point in the sky: E modes (curl free) and B modes (divergence free).

E and B modes polarization



Decomposition into E and B modes



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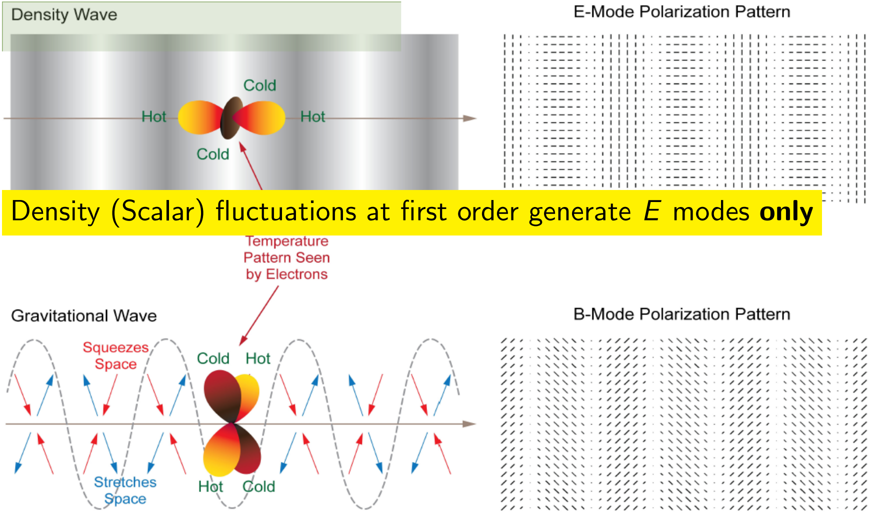

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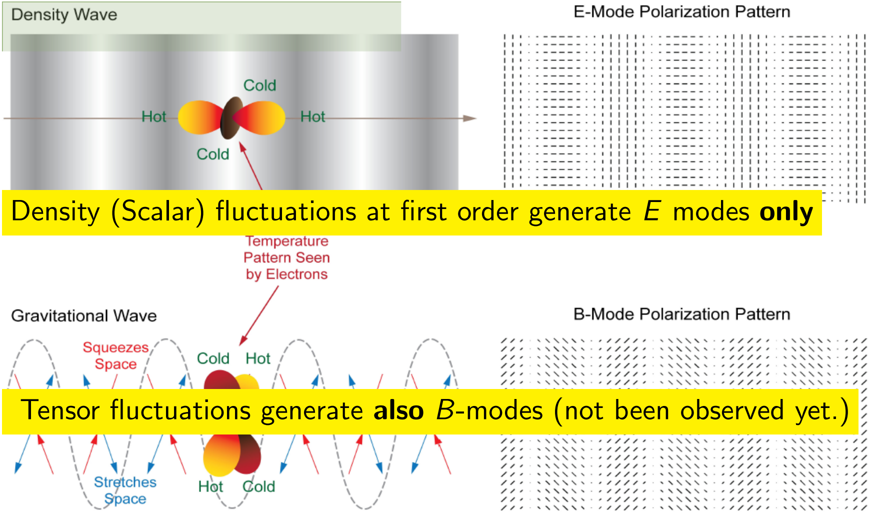

Density (Scalar) fluctuations at first order generate E modes **only**

Tensor fluctuations generate **also** B-modes (not been observed yet.)

Some remarks:

- Detection of B-modes peaking over angular scales of the order of one degree in the sky and independent of frequency would be a **footprint of primordial gravitational waves**.

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- B-modes are also expected due to lensing of E-modes. It occurs at **smaller angular scales**.
- B-modes can be generated by Faraday rotation of E-modes in primordial magnetic fields, but **depends on frequency**.
- Density fluctuations can also generate B-modes through non-linear effects that generate secondary vector and tensor modes, but with a **significantly reduced amplitude**.

Primordial B modes are smoking gun for inflation

$$\langle h^2 \rangle = \frac{V(\phi)}{M_{\rm Planck}^4} \tag{3}$$

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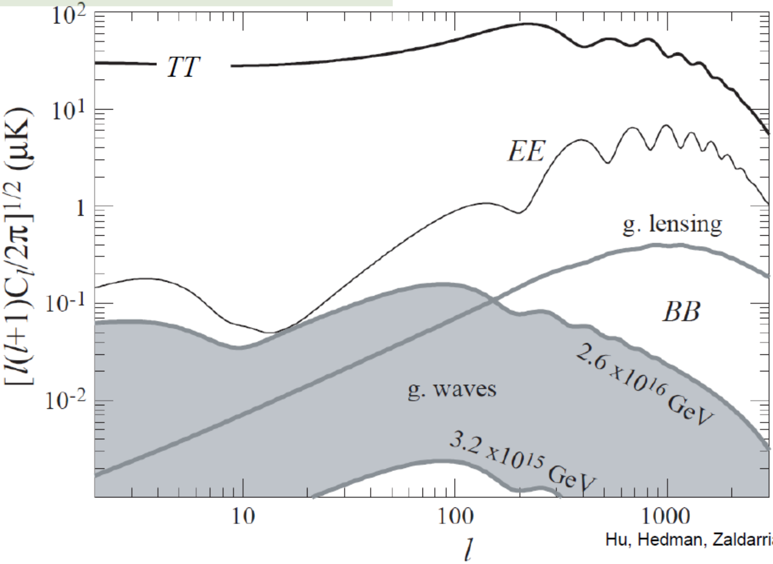
A measurement of r would reveal the presence of primordial gravitational waves, and determine the energy scale (the potential V) at which inflation took place:

$$V \approx \frac{r}{0.01} (10^{16}\mathrm{GeV})^4 \tag{5}$$

Anisotropies Angular Power Spectrum



Hu, Hedman, Zaldarriaga (2002)

The QUBIC instrument

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- **Sensitivity:**
- **Astrophysical Foregrounds:**
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- **Systematics effects:**
  Needed for:
  - accurate polarization modulation
  - detailed knowledge of instrument properties

Possible instruments

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  - Nice detectors for CMB:
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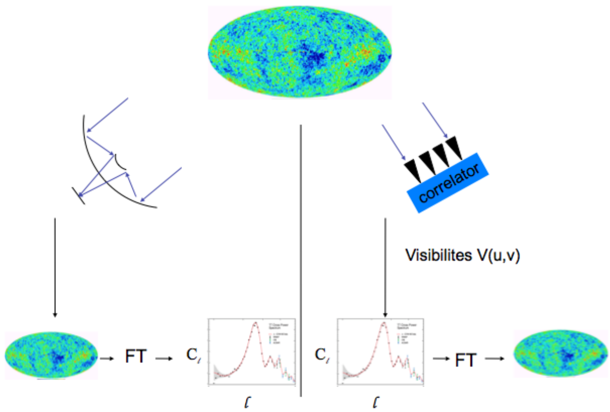
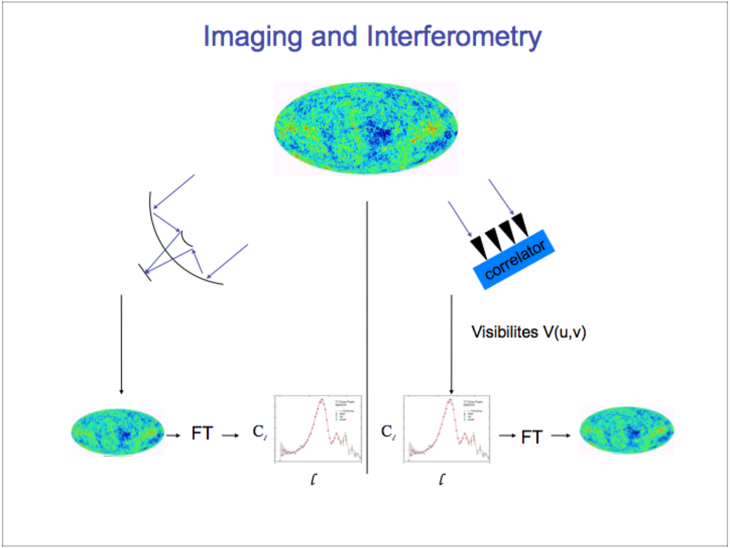
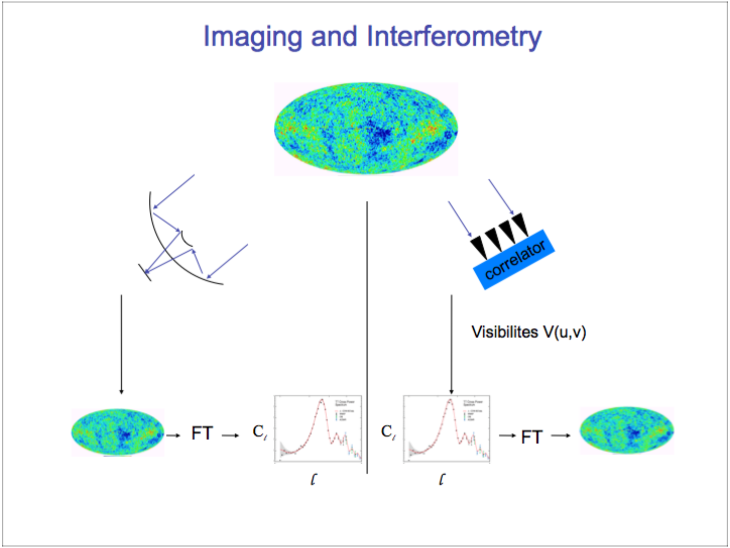
  - Technology used so far:
    - Antennas and HEMTs: higher noise
    - Correlators: hard to scale to large N_subchannels (high costs)

Imaging and Interferometry





Good sensitivity — Good control of systematics



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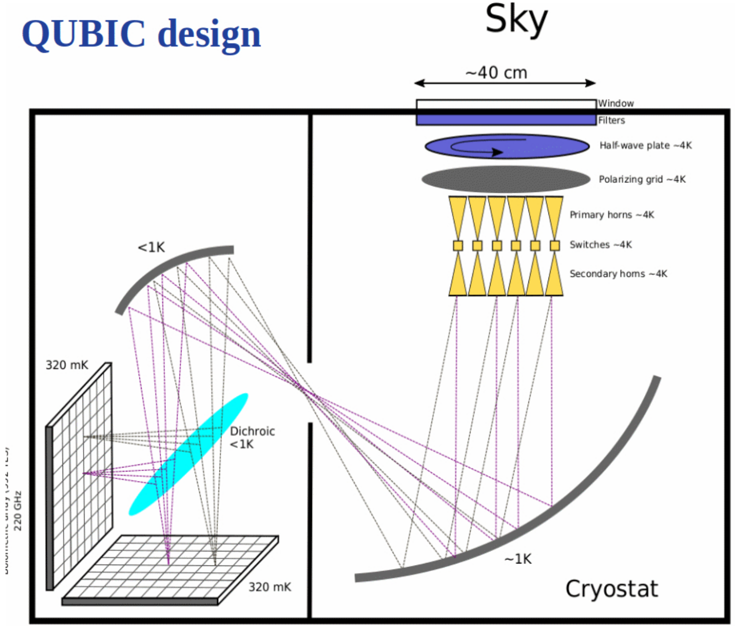
We want both characteristics!

QUBIC design



TES: Transition-edge sensor

QUBIC

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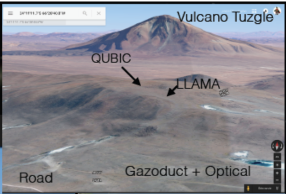
More than 90 members

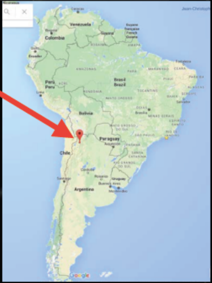
6 countries
22 labs

- APC Paris, France
- CSNSM Orsay, France
- IAS Orsay, France
- IEF Orsay, France
- IRAP Toulouse, France
- LAL Orsay, France
- Universita di Milano-Bicocca, Italy
- Universita degli studi di Milano, Italy
- Universita La Sapienza, Roma, Italy
- Maynooth University, Ireland
- Cardiff University, UK
- University of Manchester, UK
- Brown University, USA
- Richmond University, USA
- University of Wisconsin, USA
- Centro Atómico Constituyentes, Argentina
- GEMA, Argentina
- Comision Nacional de Energia Atomica, Argentina
- Facultad de Cs Astronómicas y Geofísicas, Argentina
- Centro Atómico Bariloche and Instituto Balseiro, Argentina
- Instituto de Tecnologías en Detección y Astropartículas, Argentina
- Instituto Argentino de Radioastronomía, Argentina

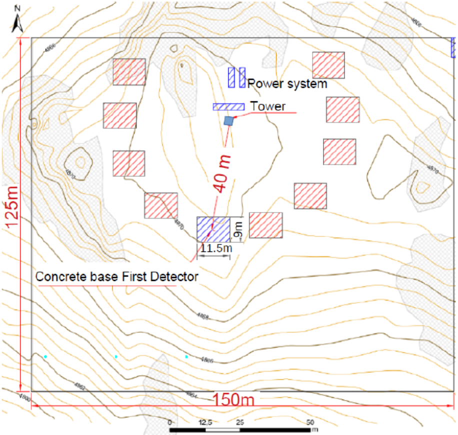
QUBIC Site

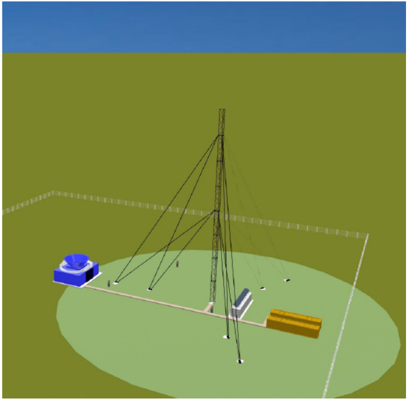
QUBIC Site:
near San Antonio de los Cobres (Salta, Argentina)

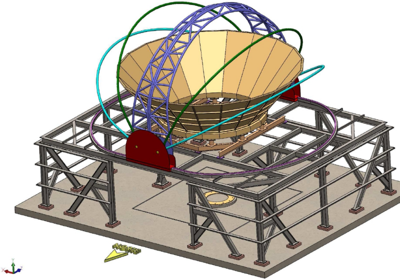


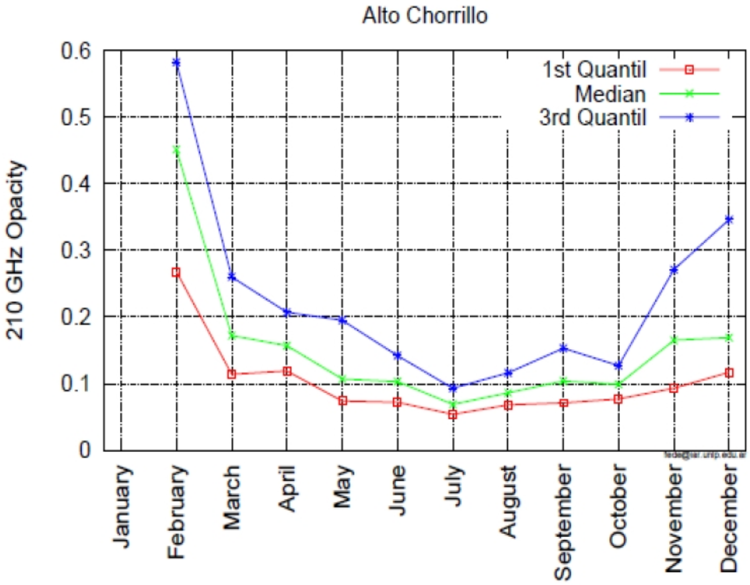


- 5000m a.s.l.
- Logistics + mount : Argentina
- NEW: Access road built up to LLAMA


N
Power system
Tower
40 m
125m
9m
11.5m
Concrete base First Detector
150m
0
12.5
25
50
m



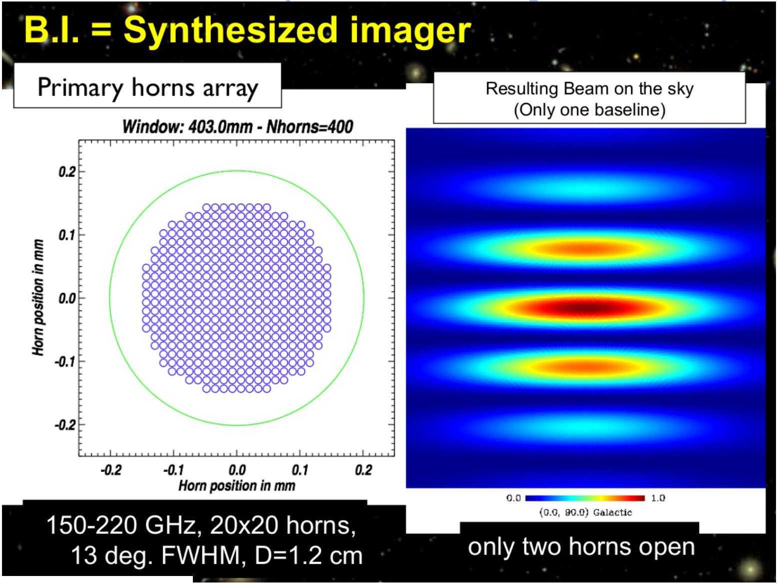




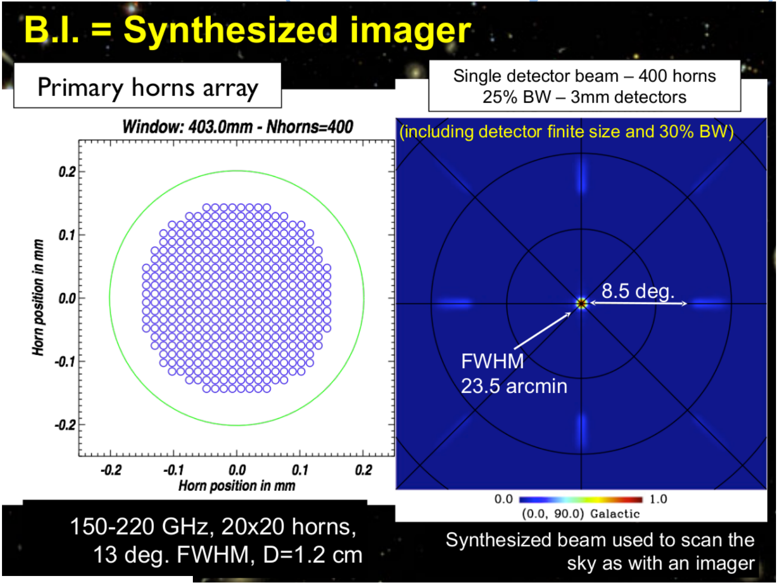
Alto Chorrillo
210 GHz Opacity
0.6
0.5
0.4
0.3
0.2
0.1
0
1st Quantil
Median
3rd Quantil
January
February
March
April
May
June
July
August
September
October
November
December

QUBIC as a synthesized imager

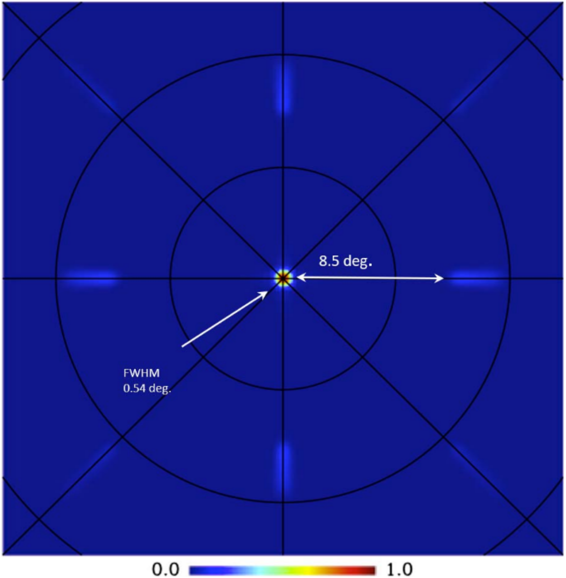
QUBIC BEAM — (Interferometry - 2 horns)



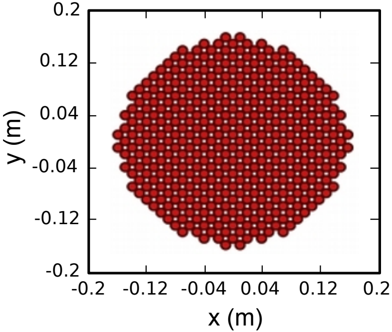
QUBIC BEAM — (Interferometry - - all horns)

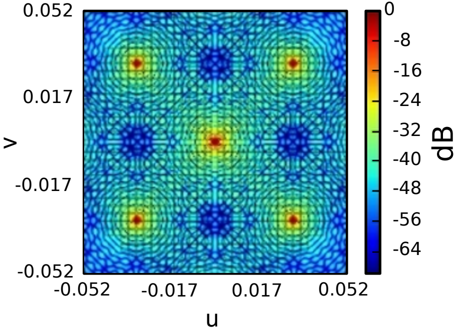


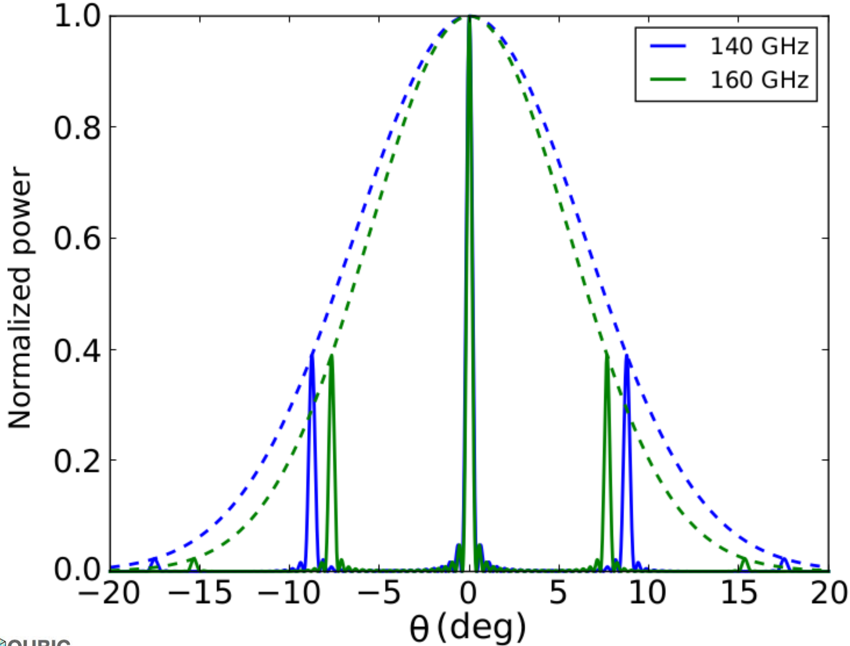
Simulated synthesized beam polycromatic



Point-source as seen in the focal plane







1.0
0.8
0.6
0.4
0.2
0.0
Normalized power
−20
−15
−10
−5
0
5
10
15
20
θ (deg)
140 GHz
160 GHz

Data Analysis more complex but richer than with a classical imager

Complex shape of synthesized beam

↓

Map-making more complex

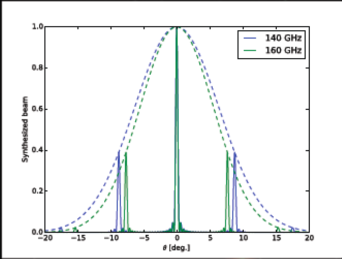
CPU...

Frequency dependence of synthesized beam

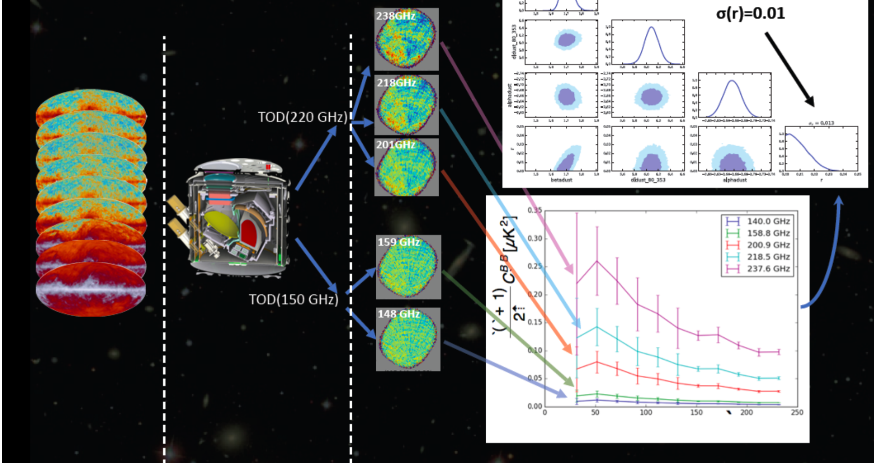
↓

Spectro-Imaging

Foregrounds!



QUBIC Spectro-Imaging



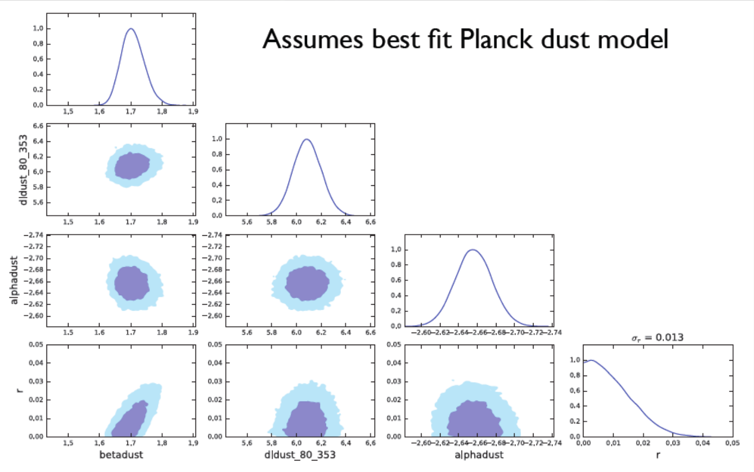
Sky:
« Infinite # bands »

Instrument:
2 wide bands

Data Analysis:
5 narrow bands

=> Increased Spectral Resolution
=> Dust subtraction

Expected Sensitivity: σ(r)~0.01



QUBIC Main Features

TES: Transition Edge Sensors

- **TES Focal planes**
  - ★ 2048 TES with NEP ~ $4\times10^{-17}\,\mathrm{W.Hz}^{-1/2}$
  - ★ 128:1 SQUIDs+ASIC Mux Readout

→ **High Sensitivity**
$r < 0.01$ @ 95%C.L.(No foregrounds)
$r < 0.02$ @ 95%C.L.(inc. foregrounds)

- **400 Elements Bolometric Interf.**
  - ★ Synthesized imaging on focal planes
  - ★ 23.5 arcmin FWHM

→ Synthesized imager scanning the sky
Perfect beam control

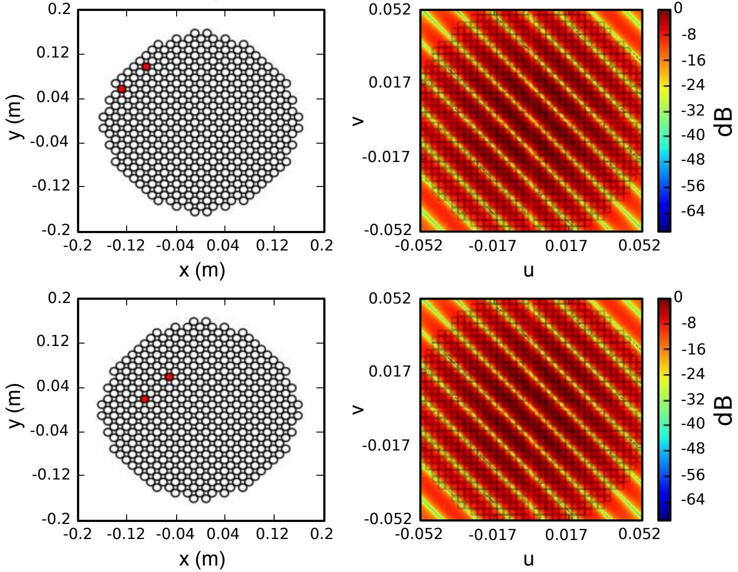
- **Dual Band operations**
  - ★ One focal plane for each band
  - ★ 150 and 220 GHz

→ Dust Polarisation contamination removal

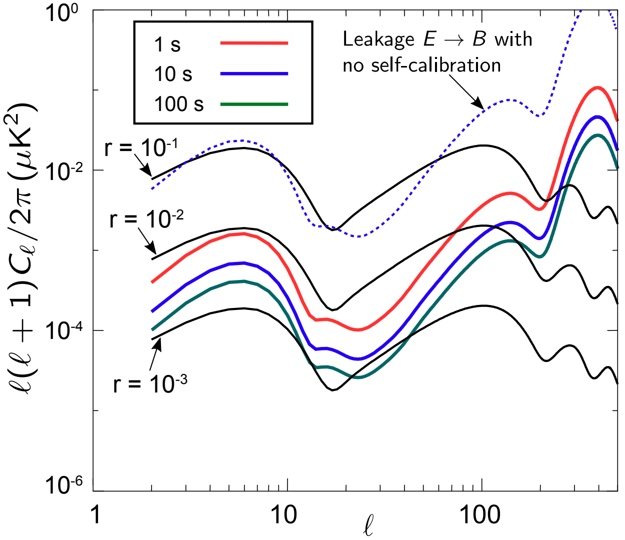
- **Switches one each horn**
  - ★ Ability to reconstruct baselines individually
  - ★ Self-Calibration like an interferometer

→ Unprecedented control of systematics with Self-Calibration

Self-calibration concept



Self-calibration performance

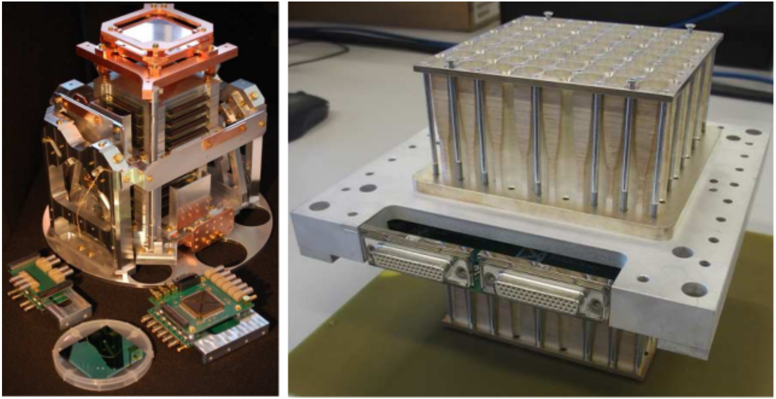


Technological Demonstrator

	TD	FI
Focal plane	1 (@150GHz)	2 (@150, 220GHz)
Detectors	1 x 256TES	2 x 1024TES
Back-to-back horns	64	400

Table 1. Main difference between TD and FI.

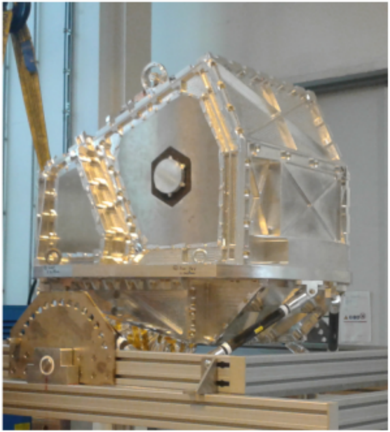
Current status - Instrument calibration



(a) (b)

Panel (a) shows one of the two cryogenic detection chains. On top of the chain, one can see the TES focal plane. Panel (b) shows the array of the 64 + 64 back-to-back dual-band corrugated horns interfaced with the switch array.

Current status - Instrument calibration

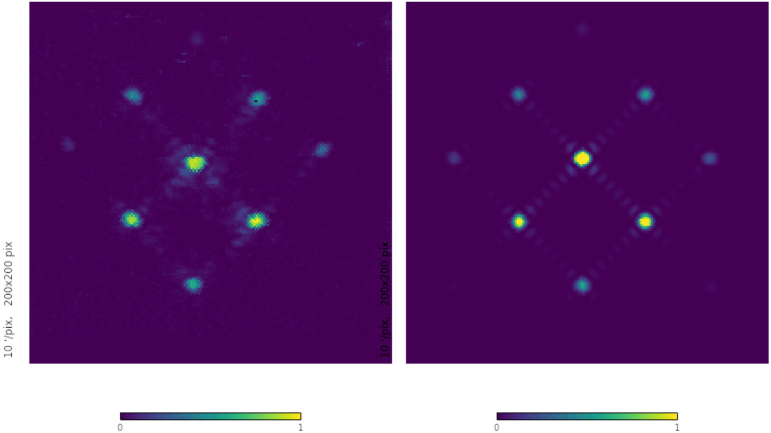


(c)

(d)

Panels (c) and (d) show the 1 K box before and during the integration into the QUBIC cryostat.

Current status - Observed beam



Comparison between the synthesised beam measured with one of the TES in the technological demonstrator (left panel) and the predicted beam without aberration effects (right panel).
(see Martín Gamboa's poster)

Angular resolution as a function of frequency

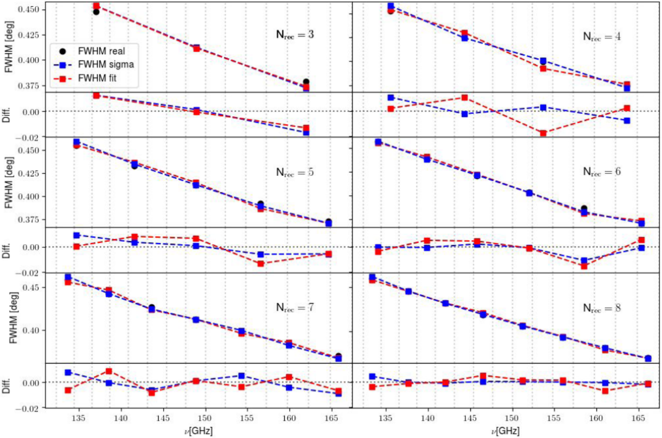


Fig. 7. Angular resolution (FWHM) measured with two independent methods (*sigma* in blue and *fit* in red lines). Dashed line shows the frequency used to simulated the TOD in simulations. Black dots are represents the theoretical angular resolution in the frequencies of sub-band reconstruction.

(see Martín Gamboa's poster)

Beam as a function of frequency

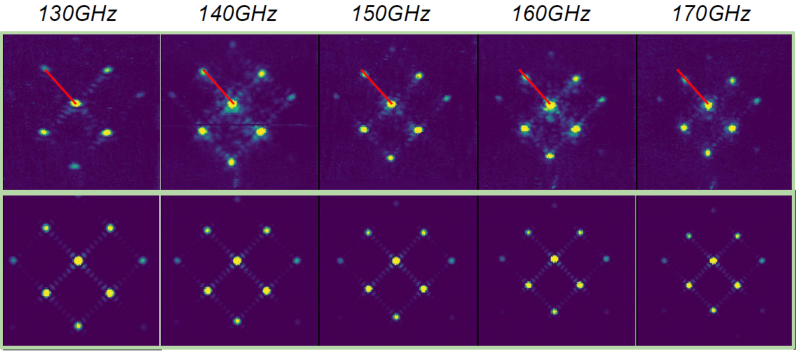


Fig. 6. Upper row: real measurements with TD. Lower row: Theoretical SB. Redline is a rule to see easily how the secondary peaks close to the center when the frequency rises as is expected.

(see Martín Gamboa's poster)

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    - only one-quarter of the 150 GHz TES focal plane
    - array of 64 + 64 horns, 64 switches and a smaller optical combiner.
    - The TD will not produce science, but it will demonstrate the feasibility of the bolometric interferometry both in the laboratory and in the field.

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- The deployment of QUBIC final instrument is foreseen to be completed by 2020.

Summary

- QUBIC is a new way to measure the polarization of the CMB.
- It combines the sensitivity of TES bolometric arrays with the control of systematic effects that are typical of interferometers.
- The design of QUBIC allows for self-calibration and spectral imaging.
- A **technological demonstrator** is currently being tested in the laboratory and will soon be deployed in Argentina for a first-light test.
- We forecast the installation of the **final instrument** and the start of scientific operations during 2020, opening the way for a new generation of instruments in the field of CMB polarimetry.

Thanks for your attention!!