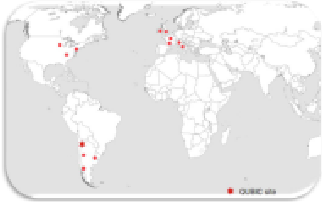

APC Paris, France
C2N Orsay, France
CSNSM Orsay, France
IAS Orsay, France
IRAP Toulouse, France
LAL Orsay, France
Università di Milano-Bicocca, Italy
Università degli studi di Milano, Italy
Università La Sapienza, Roma, Italy
Maynooth University, Ireland
Cardiff University, UK
University of Manchester, UK
Brown University, USA
Richmond University, USA
University of Wisconsin, USA
Centro Atómico Constituyentes, Argentina
GEMA, Argentina
Comisión Nacional de Energía Atómica, 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

a Q&U Bolometric Interferometer for Cosmology

Lorenzo Mele for the QUBIC collaboration:

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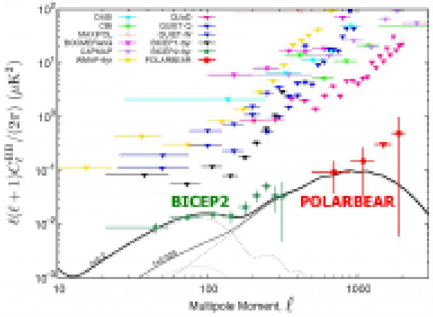
The Q & U Bolometric Interferometer for Cosmology (QUBIC) [1] is a ground-based experiment aimed at detecting the trace of *Cosmic Inflation*, imprinted as a B-mode polarization in the Cosmic Microwave Background (CMB) [2]. Since the signal amplitude is extremely small, a few nK assuming a tensor-to-scalar ratio r=0.01, very sensitive detectors are needed and extreme control of foregrounds and systematic effects is necessary. QUBIC is designed to face all these aspects exploiting Bolometric Interferometry: a novel implementation, combining the sensitivity of bolometric detectors with the excellent beam-forming capabilities of a Fizeau interferometer, allowing great control over systematic effects. The current upper-limit on primordial B modes is r < 0.07 at 95% C.L. [3]. QUBIC, with Planck 353 GHz information [4], will lower the constraint to r=0.02 at 95% C.L. The experiment is currently in the calibration phase at APC Paris, QUBIC will be deployed to the site of Alto Chorillos (4.900m a.s.l.), near San Antonio de los Cobres, Argentina, during the 2019.

Looking for Cosmic Inflation

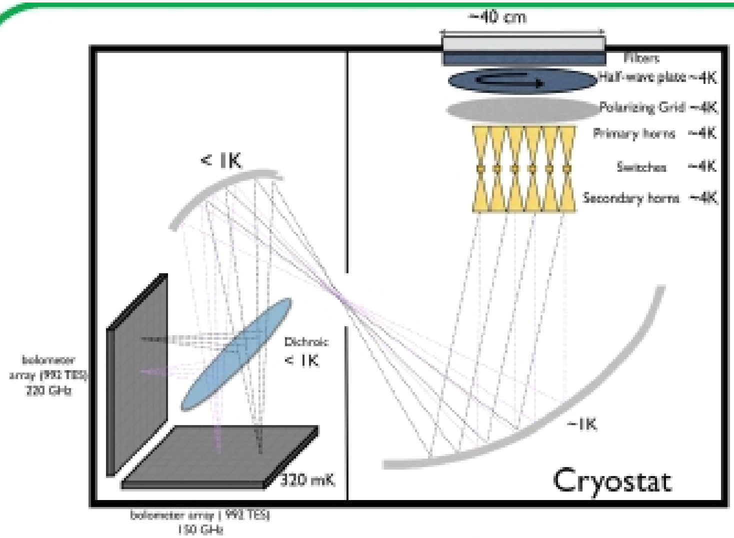
An inflationary phase of accelerated expansion in the early Universe is among the theories able to explain the paradoxes of the Standard Model of the Big Bang. The CMB provides an indirect way to probe Cosmic Inflation, since the primordial gravitational waves (PGWs) produced are expected to have imprinted a signature in the CMB photons as a linear polarization through anisotropic Thompson scattering. Stokes parameters Q and U are tied to the coordinate system; it is then preferred to use a coordinate-system-independent representation of polarization, defined as E and B modes [5]. While scalar fluctuations produce only E-modes, tensor fluctuations, as the PGWs, produce both B-modes and E-modes.

A detection of B-modes would thus represent compelling evidence for Cosmic Inflation, and the measured level would point to its energy scale.



BICEP2 Collaboration

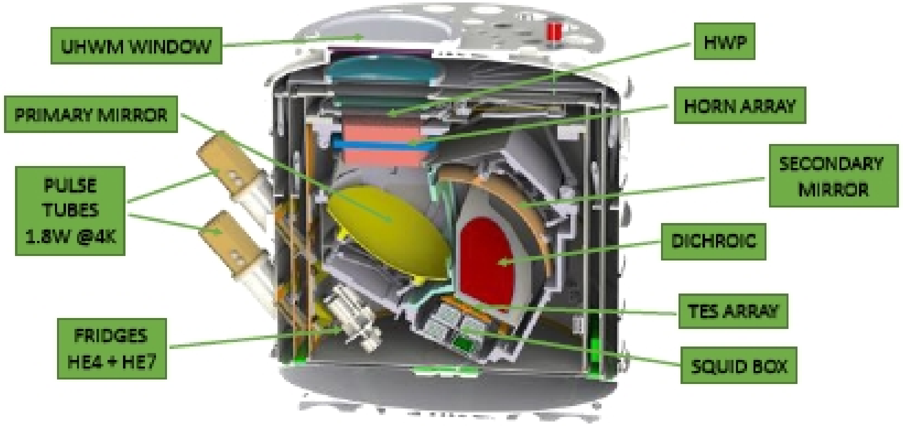
The Instrument



HWP + polarizer = Stokes polarimeter

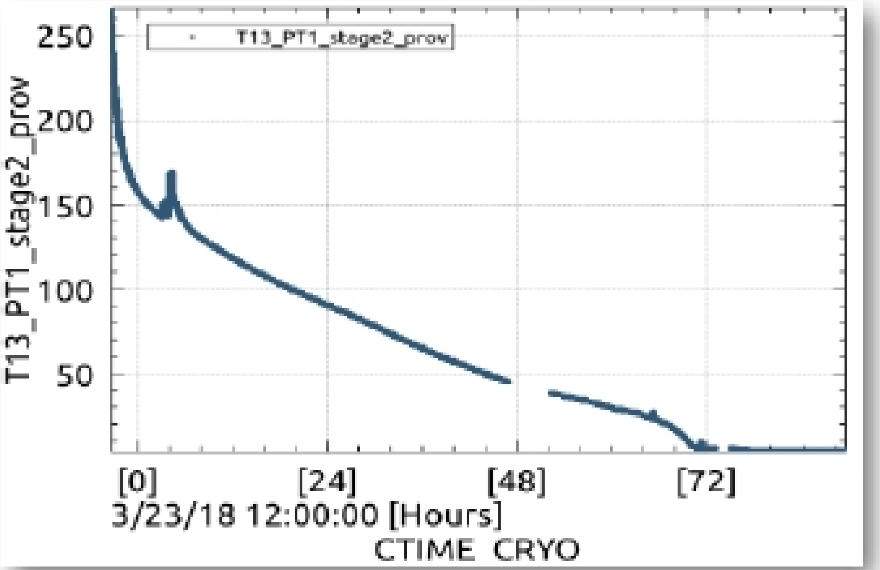
polarization modulation before optical system

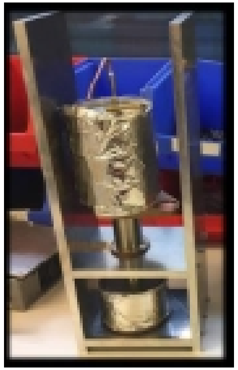
Horns aperture array + Optical beam combiner = interferometer



The Cryogenic System

Cryostat with three shells: vacuum shell, radiative shell (40K) and 4K shell. Two parallel Pulse Tube refrigerators (double stage 40K and 4K). The 1K-Box (beam combiner, polarizing analyzer and horns arrays) is cooled down by an 4He refrigerator. A 3He + 4He fridge provides 300mK temperature for the TES arrays (1024 TES for each focal plane) [7].

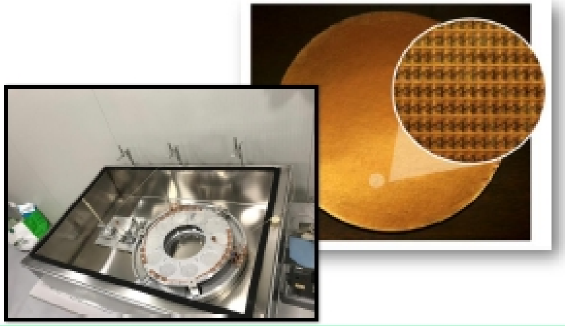


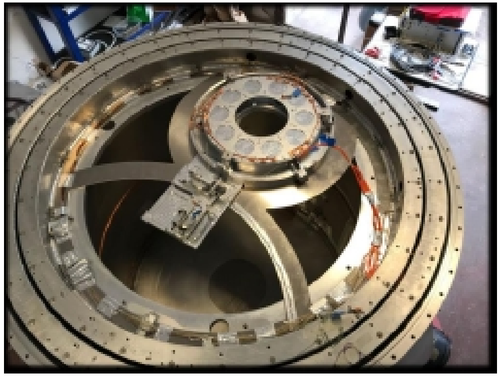


Polarization Modulation System

The incoming polarized signal is modulated by a stepped Dielectrically Embedded-Mesh Half-Wave-Plate (HWP) [8] mounted in a cryogenic rotator operating at 4K. The rotator has been qualified in liquid nitrogen (77K).

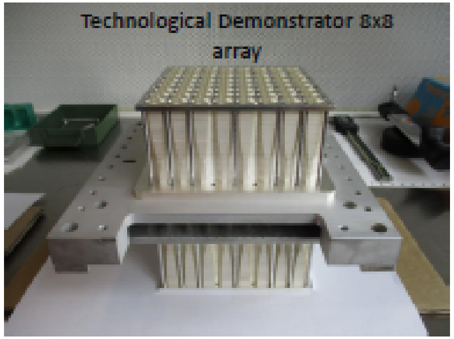
$$S_{det} = \frac{1}{2}[S_I + S_Q\cos(4\theta_{HWP}) + S_U\sin(4\theta_{HWP})]$$



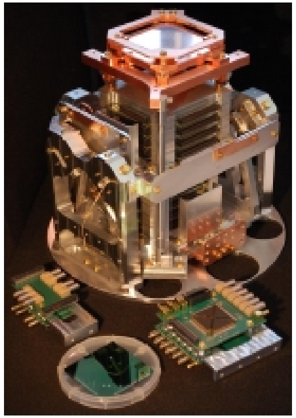


Horns and Switch Arrays

The input apertures array is composed of high-quality corrugated back-to-back feedhorns, made using the platelets technique. The system is complemented by an array of switches, allowing each aperture to be individually commanded opened or closed, thereby obtaining any possible aperture configurations of two horns shut at the same time.



Detection System



Each focal plane:

4 of 256 TESes @300mK

Readout:

Time Domain Multiplexing 128:1

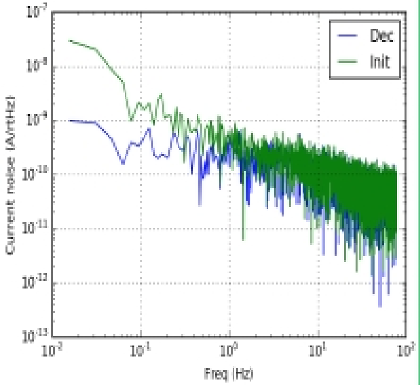
128 SQUIDs @ 1K + 1 ASIC @ 40 K for ⅛ focal plane

Custom cryogenic ASICs [9]

Measured Performance:

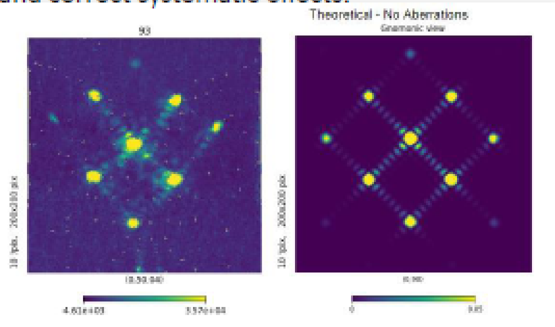
NEP < 5.10^{-17}W $Hz^{-0.5}$

τ < 10ms



Synthesized Beam

QUBIC observes interference fringes formed by 400 horns with two arrays of Transition Edge Sensors (TES) operating in two frequency channels centered at 150 GHz and 220 GHz. The image on each focal plane is a synthesized image of the sky, where only specific Fourier modes are selected by all the pairs of horns. The synthesized beam consists of a primary beam (FWHM = 0.8°) and secondary beams spaced by 8.4°. In the figure below we plot measured interferometry patterns, obtained with the QUBIC Technological Demonstrator observing a point source in the far field of the instrument, compared to what is expected. The interferometric nature of the instrument allows for the use of the *self-calibration* technique [6], a powerful tool to detect and correct systematic effects.



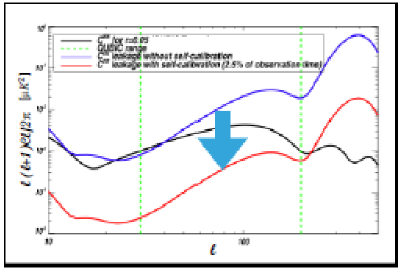
Self-Calibration

Each horn pair defines a *baseline*, i.e. a Fourier mode of the sky, and forms interference fringes on the focal planes. Equivalent baselines (pairs of horns with the same separation and orientation) should produce the same fringe patterns in absence of systematics.

In this way systematic effects from the beam, optics, misalignments can be identified and corrected.

- Horn Location $\vec{x_i}$
- Horn Transmission $g_\eta(\vec{x_i})$
- Horn Cross-Polarization $e_\eta(\vec{x_i})$
- HWP Transmission & Cross Polarization h_η, ε_η

parameters	No Self Cal.	1 day / year		100 days/year	
	$\sigma_{nominal-real}$	$\sigma_{real-recovered}$	ratio	$\sigma_{real-recovered}$	ratio
$\vec{x_i}$	$100. \times 10^{-6}$	5.86×10^{-5}	17	2.27×10^{-8}	4402
$g_\eta(\vec{x_i})$	0.0001	1.36×10^{-6}	73	1.22×10^{-8}	8182
$e_\eta(\vec{x_i})$	0.0001	1.09×10^{-6}	92	1.20×10^{-8}	8280
h_η	0.01	1.18×10^{-4}	84	7.27×10^{-6}	1375
ξ_η	0.01	1.24×10^{-4}	80	5.81×10^{-6}	1722



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