The QUBIC experiment
the Q U Bolometric Interferometer for Cosmology

Elia Stefano Battistelli on behalf of J.-Ch. Hamilton, for the QUBIC collaboration
What is QUBIC?

QUBIC is a millimeter-wave bolometric interferometer for cosmology. It aims to observe the Cosmic Microwave Background Radiation Polarization through B-mode experiments.

QUBIC collaboration, 2011, APP, 34, 705-716
Piat et al, 2012, JLTP 167, 872P

B-mode
RADIATION + BOLOMERIC = BOLOMERIC INTERFEROMETER

Q BOX
U BOX

mm interferometric experiments to observe the Cosmic Microwave Background Radiation Polarization
QUBIC collaboration

+ China (IHEP & PMO) about to join QUBIC
QUBIC collaboration

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QUBIC
QU Bolometric Interferometer for Cosmology

SCAR - Astronomy and Astrophysics from Antarctica
Siena, Italy, July 2013
Inflation

Last scattering surface

Planck CMB latest map

No Gravitational waves (r = 0)

30 degrees
3.47µK

SCAR - Astronomy and Astrophysics from Antarctica
Siena, Italy, July 2013
Planck CMB latest map

Gravitational waves ($r=0.3$)

30 degrees

3.47µK

Inflation

Last scattering surface

SCAR - Astronomy and Astrophysics from Antarctica
Siena, Italy, July 2013
Inflation

the SCIENCE

Sensitivity

Systematics

Hu et al. 2002
Expected difficulties in the B-Modes Quest

- **Sensitivity**:  
  - B polarization is at best 10 times weaker than E  
  - Amplitude could be very small …  
  - 1 year of Planck is ~ S/N=1 for T/S=0.01  
  - A dedicated space mission might not be for tomorrow….  
  - …and might never be if no proof of concept demonstrated

- **Foregrounds**:  
  - Need to remove them accurately (can’t just mask)  
    - Multiwavelength instruments  
  - Observe an ultra-clean region  
    - can’t be too small as primordial B modes are mainly on large scales

- **Systematic effects**:  
  - Instrument induces leakage of T into E and B (and T>>E>>B)  
    - Cross-polarization, beams and ground pickup are major issues  
  - Need accurate polarization modulation and detailed knowledge of instrument properties
QUBIC Site: Dome C

Great landscape

Courtesy L. Valenziano

PWV (mm)
0
1

Great for CMB observations!

Healthy weather
BRAIN: site testing

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

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

CIRCULAR POLARIZATION < 0.19 %

LINEAR POLARIZATION < 0.11 %
Possible instruments

- **Imagers with bolometers (thermal):**
  - No doubt they are nice detectors for CMB:
    - wide band
    - low noise
  - Especially true for a satellite (small background)

- **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
    - Correlators: hard to scale to large #channels

- **Can these two nice devices be combined?**

  ➡ Bolometric Interferometry!
QUBIC design

fringes successfully 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

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Zotefoam 45x20cm window
Polypropilene thin layer on top
A. Schillaci leading the effort
THE INSTRUMENT

Dielectrically embedded mesh HWP
G. Pisano et al. 2012

window
Filters
Half-wave plate

Ø=20cm

340mm
382mm
430mm
400 primary horns, FWHM = 14°
30µm mounting accuracy
Second prototype to be tested soon
THE INSTRUMENT

400 electro-magnetic switches
mainly used for self-calibration

 Courtesy G. Bordier

window
Filters
Half-wave plate
Primary horns

Switches

APC, Univ. Manchester, Univ. Milano, Univ. Bicocca
THE INSTRUMENT

Off-Axis Gregorian System
300mm equivalent focal length
0.5m mirrors
Low aberrations

Fig. Grasp simulation of the optical system of QUBIC

Maynooth University, Rome University

Scottish association for research in Antarctica

NUI Maynooth

THE INSTRUMENT
THE INSTRUMENT

TES + SQUIDs + SiGe ASIC Mux
2 arrays of 992 NbSi TES
Time Domain Multiplexing

Resistance

$R_N$  
$R_C$

Temperature $T_c$

window
Filters
Half-wave plate
Primary horns
Switches
Secondary horns

Beam Combiner

Detectors
THE INSTRUMENT

**QUBIC**
QU Bolometric Interferometer for Cosmology

**SCAR**
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### Detectors
- TES + SQUIDs + SiGe ASIC Mux
- 2 arrays of 992 NbSi TES
- Time Domain Multiplexing

- Detector array at 300mK
- Flex PCB
- SQUIDS

### Other Components
- Beam Combiner
- Window
- Filters
- Half-wave plate
- Primary horns
- Switches
- Secondary horns

APC, CSNSM, IRAP
THE INSTRUMENT

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWP</td>
<td>4 K</td>
</tr>
<tr>
<td>Horn Arrays</td>
<td>4 K</td>
</tr>
<tr>
<td>Primary mirror</td>
<td>4 K</td>
</tr>
<tr>
<td>Secondary Mirror</td>
<td>1 K</td>
</tr>
<tr>
<td>Polarizing grid</td>
<td>0.3 K</td>
</tr>
<tr>
<td>Detector arrays</td>
<td>0.3 K</td>
</tr>
<tr>
<td>Read out electronics</td>
<td>1 K and 77 K</td>
</tr>
</tbody>
</table>

P. de Bernardis
S. Masi

Cryostat

Rome University

Pulse Tube

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Systematics: Self-Calibration

- Unique possibility to handle systematic errors
  - 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
  - Unique specificity of Bolometric Interferometry!
  - Example: exact horns locations (figure exaggerated !!)

Either a passive or an active source will be used depending on the TES background we request.

Redundant baselines: same Fourier Mode

QUBIC QU Bolometric Interferometer for Cosmology

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B.I. = Synthesized imager

Primary horns array

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

Synthesized beam

8.5 deg. FWHM

Synthesized beam used to scan the sky as with an imager
Self-Calibration results

\[ C^{BB}_{EE} \text{ for } r=0.05 \text{ (QUBIC Target)} \]
\[ C^{BB}_{EE} \text{ leakage without self-calibration} \]
\[ C^{BB}_{EE} \text{ leakage with self-calibration (2.5\% of observation time)} \]

initial $E \rightarrow B$ leakage
residual $E \rightarrow B$ leakage

QUBIC timeline

- 2012: Partially funded by French ANR
- 2013: Construction started for the 1st module
- 2014: Integration and calibration
- 2015: First light at Dome C
- Data taking: one to two years (incl. winter) with one module
- 2017...: Full QUBIC construction: 6 modules at 90, 150 and 220 GHz
tensor/scalar ratio sensitivity

- Planck TT + WMAP Pol + HighL + BAO
- WMAP7y
- QUBIC 1 Module
- QUBIC 6 Modules

90% C.L. upper limit on Tensor to scalar ratio $r$
Summary

- QUBIC is a novel instrumental concept
  - Bolometric Interferometer optimized to handle systematics

- QUBIC is a synthesized imager 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

- **Target:**
  - First module (150 GHz): \( r < 0.05 \) at 90% C.L. (first light late 2015)
  - Six modules (90, 150, 220 GHz): \( r < 0.01 \) at 90% C.L.
Map Making ~ as an imager

- Scan the sky with synthesized beam
  - Az. scans at constant elevation following a single field
  - Phi rotation around optical axis

- Reproject data on the sky

- QUBIC Synthesized beam has multiple peaks
  - Usual map making assumes $A$ has a single non-zero element in each column
    - Does not lead to good results
  - Improved method with better beam approximation
    - Sparse matrices helps fast convergence of CG

[Image of convolved original map and reconstructed map with text: Pierre Chanial @ APC]
Power spectra from simulated QUBIC Maps

\[ n(\ell+1)C_\ell/(2\pi) \]

\[
\begin{array}{c}
0.035 \\
0.030 \\
0.025 \\
0.020 \\
0.015 \\
0.010 \\
0.005 \\
0.000 \\
-0.005 \\
0.000 \\
50 \\
100 \\
150 \\
200 \\
250 \\
300 \\
350 \\
400 \\
\end{array}
\]

\[ \ell \]

Average on 100 realizations of pure primordial B modes

NB: arbitrary noise level and scanning strategy