

Exploring the primordial Universe with QUBIC

the Q U Bolometric Interferometer for Cosmology



J.-Ch. Hamilton (APC - Paris, CNRS/IN2P3)
On behalf of the QUBIC Collaboration



QUBIC

QU Bolometric Interferometer for Cosmology

CMB foregrounds for B-mode studies

Tenerife, Spain, October 15-18, 2013

J.-Ch. Hamilton





QUBIC

a Q&U Bolometric Interferometer for Cosmology



- APC Paris, France
- C2N Orsay, France
- CSNSM Orsay, France
- IAS 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
- 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

*130 Collaborators
22 laboratories
6 countries*

+SISSA Joining!



★ QUBIC site



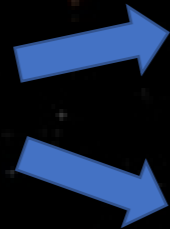
Primordial B-modes with QUBIC

Very weak
signal



- **Focal Plane:**
 - 2048 TES with NEP $\sim 4 \times 10^{-17}$ W.Hz^{-1/2}
 - 128:1 SQUIDs+ASIC Mux Readout
 - End-To-End Sims. show $\sigma(r)=0.01$ with 2 years

Instrumental
systematics



- **Cryogenic Optics after HWP and Polarizer + Full power detectors**

➤ Instrumental Polarization has no effect

- **400 elements Interferometer**

- Synthesized Imaging (well controlled beam) – angular resolution 23.5 arcmin
- **Self-Calibration** using switches + active source

Polarized
foregrounds



- **Two wide bands: 150 and 220 GHz**
 - 1 focal plane for each channel
- **Spectro-Imaging allows to form $\geq 2+3$ bands**
 - Increased Frequency Resolution
 - More Complex dust models can be constrained



QUBIC

QU Bolometric Interferometer for Cosmology

CMB foregrounds for B-mode studies

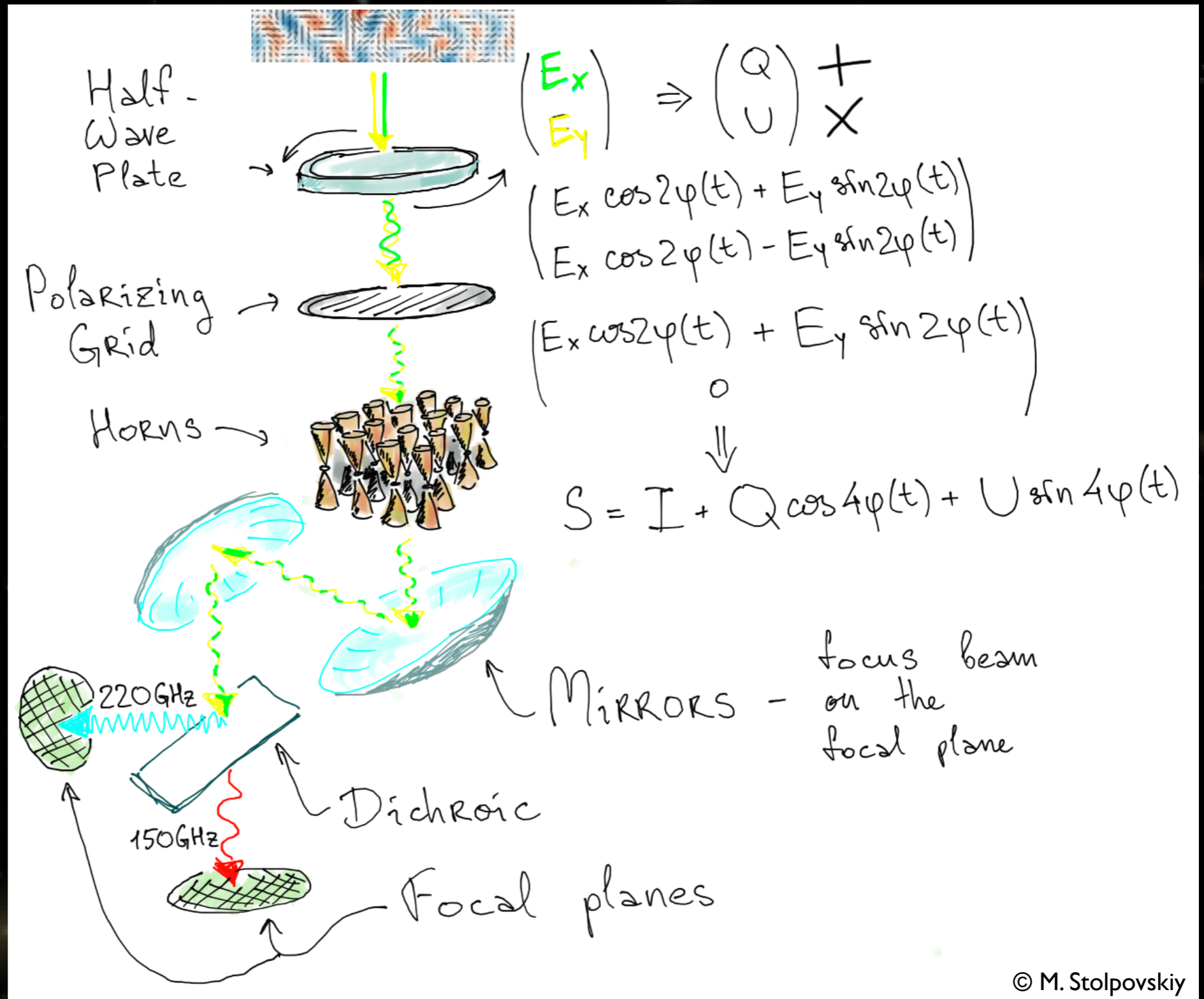
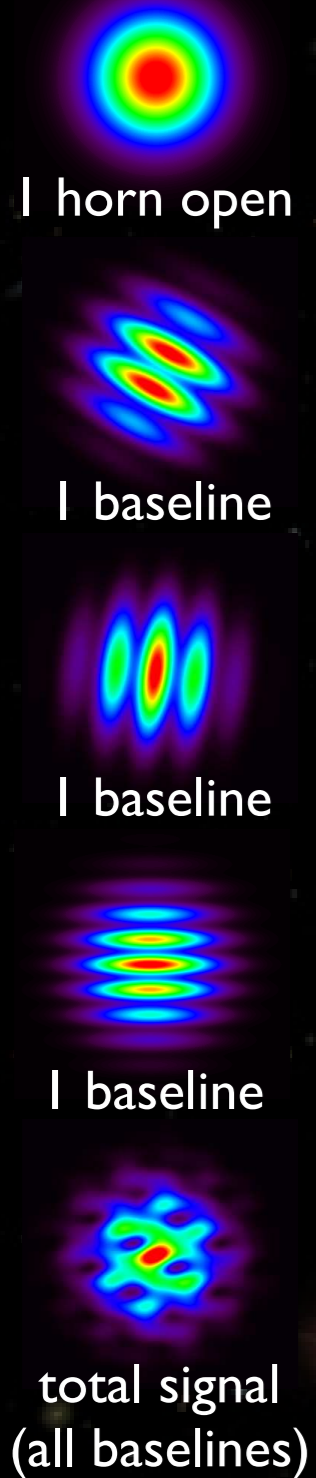
Tenerife, Spain, October 15-18, 2013

3

J.-Ch. Hamilton



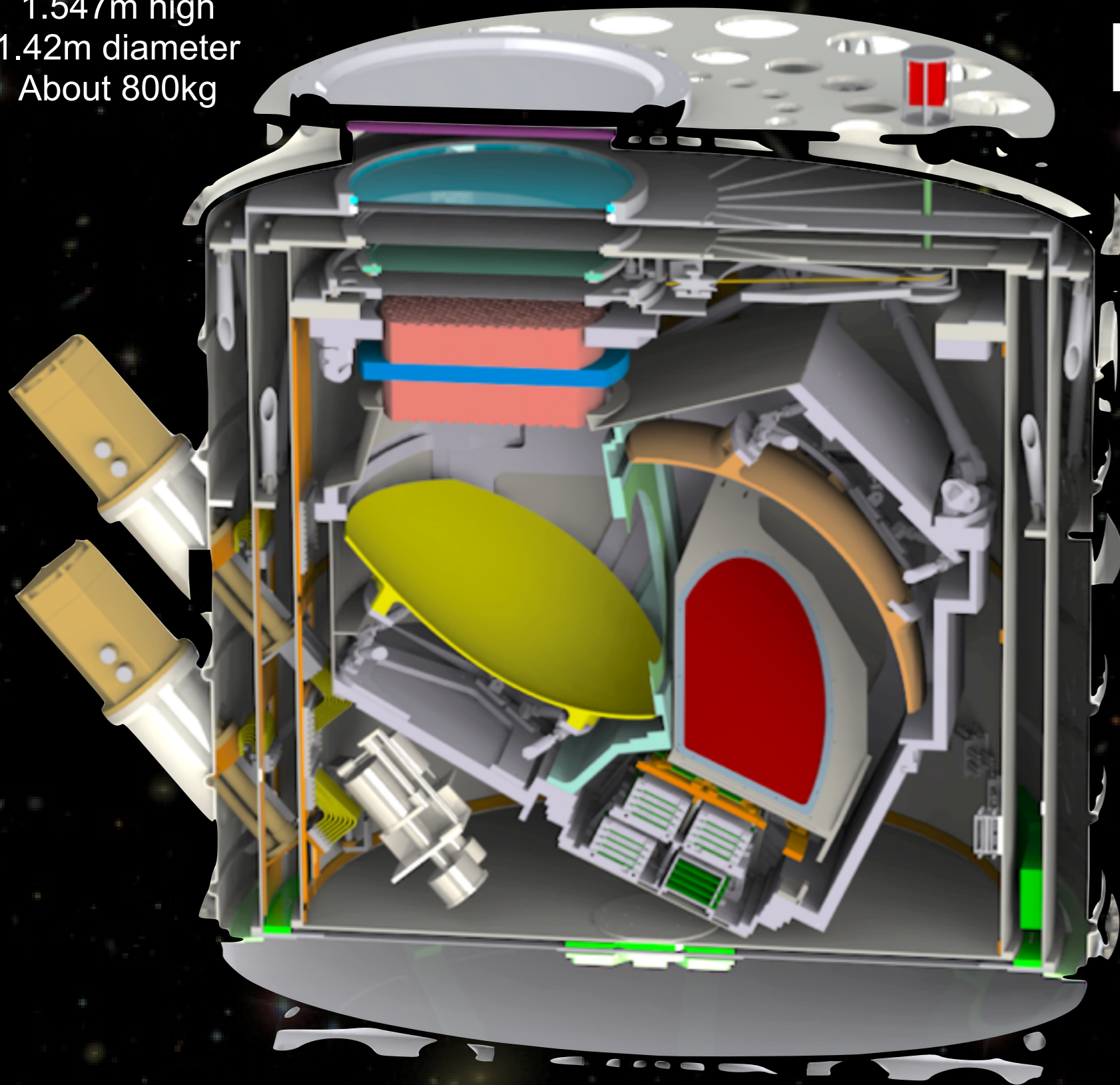
QUBIC concept: Quasi optical correlator



© M. Stolpovskiy



1.547m high
1.42m diameter
About 800kg



Integration being finalized in Paris

- Outer cryostat: Roma
- IK Box / detectors: APC, CSNSM / IRAP
- Fridges: Manchester
- Optics: Roma / Maynooth / Cardiff

1st integrated
(detectors, optics,...)
cooldown this week



QUBIC

QU Bolometric Interferometer for Cosmology

5

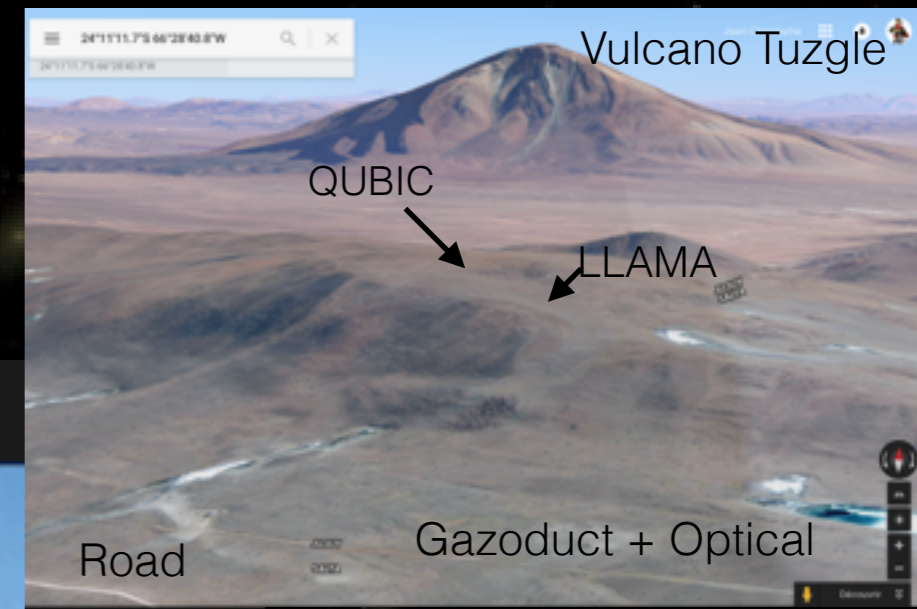
CMB foregrounds for B-mode studies

Tenerife, Spain, October 15-18, 2013

J.-Ch. Hamilton



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



- 5000m a.s.l.
- Logistics + mount : Argentina
- Access road built, works started on site and in Salta city (integration hall)



QUBIC

QU Bolometric Interferometer for Cosmology

CMB foregrounds for B-mode studies

Tenerife, Spain, October 15-18, 2013

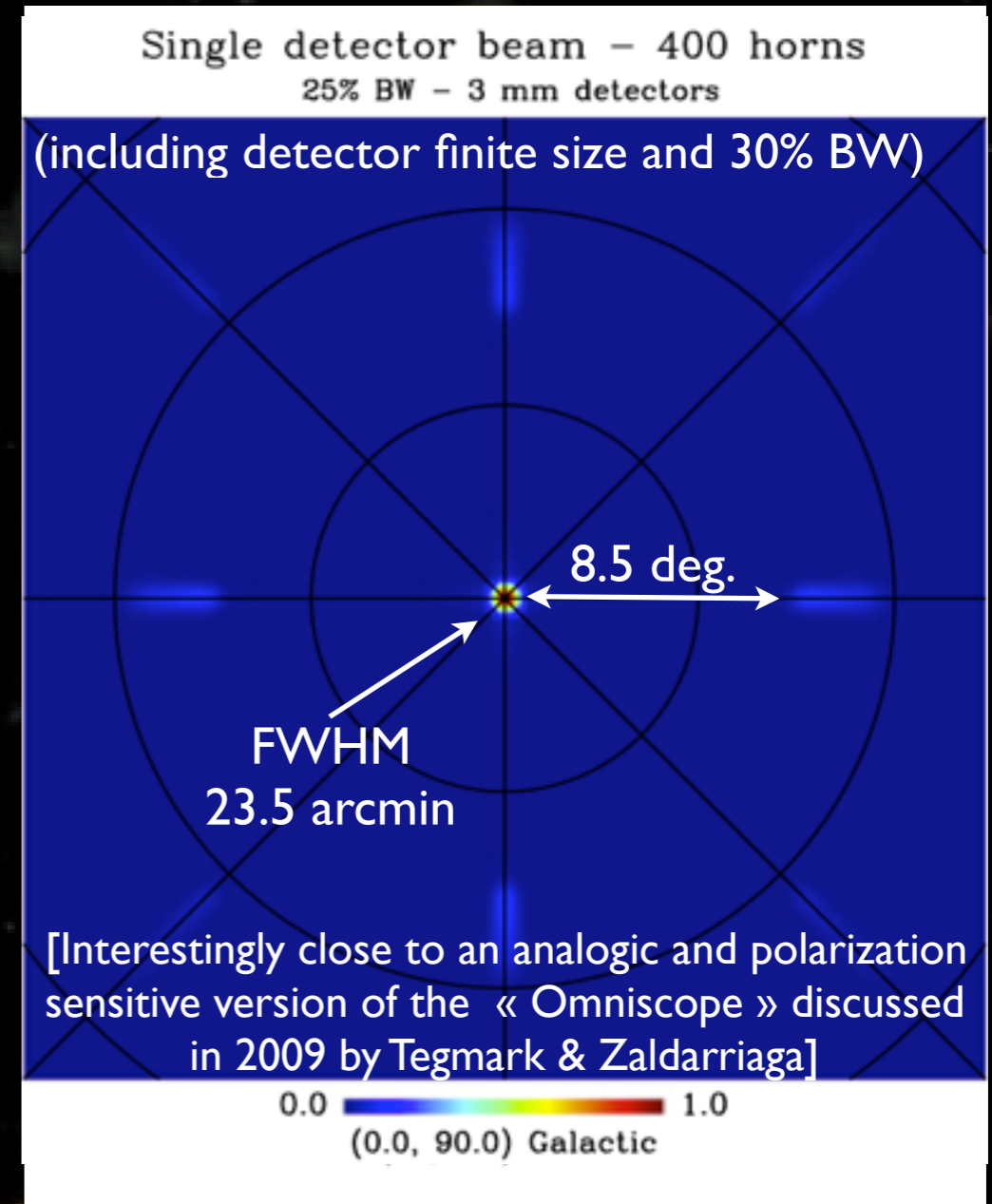
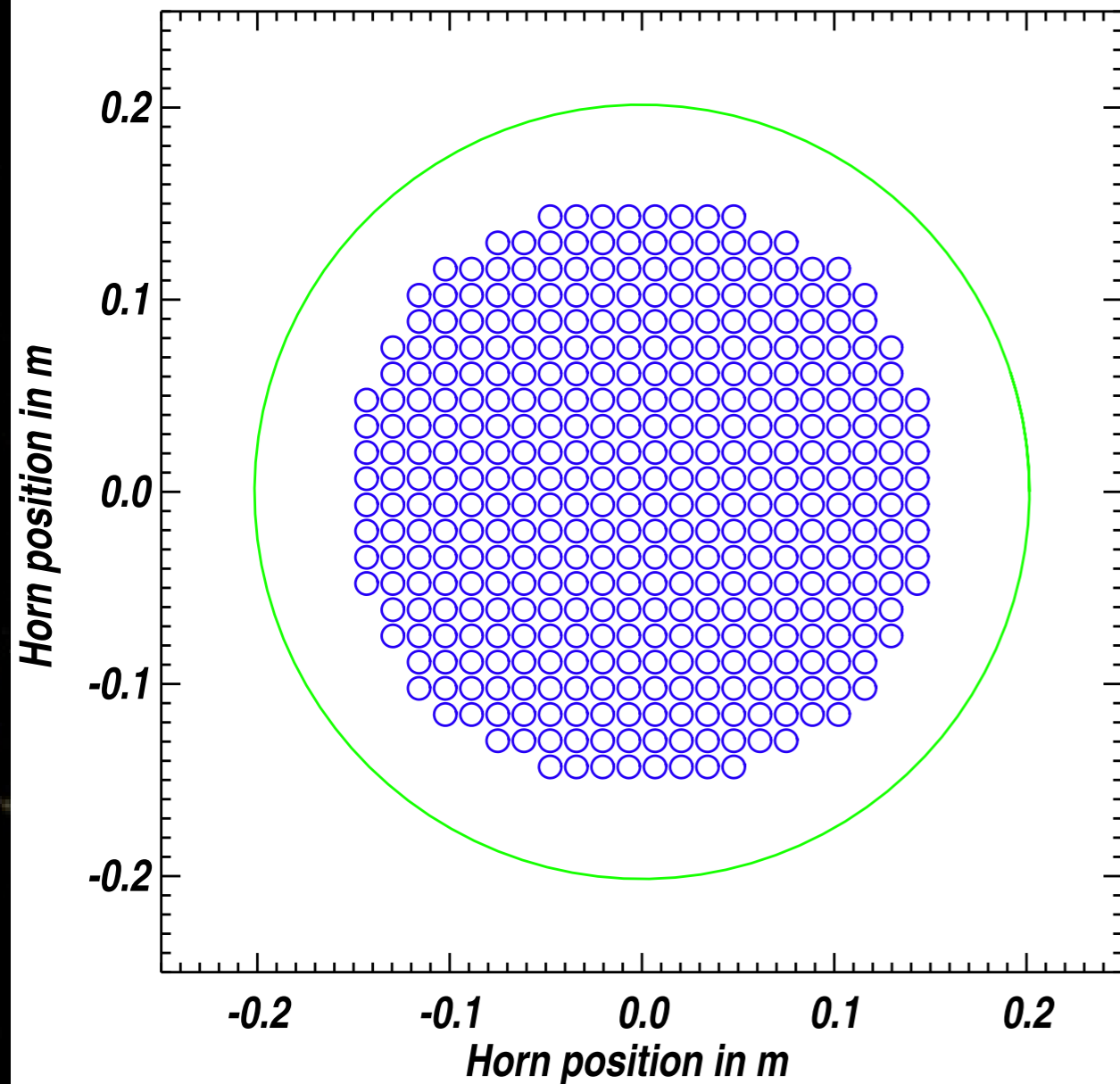


B.I. = Synthesized imager

Primary horns array

Synthesized beam (on the sky)

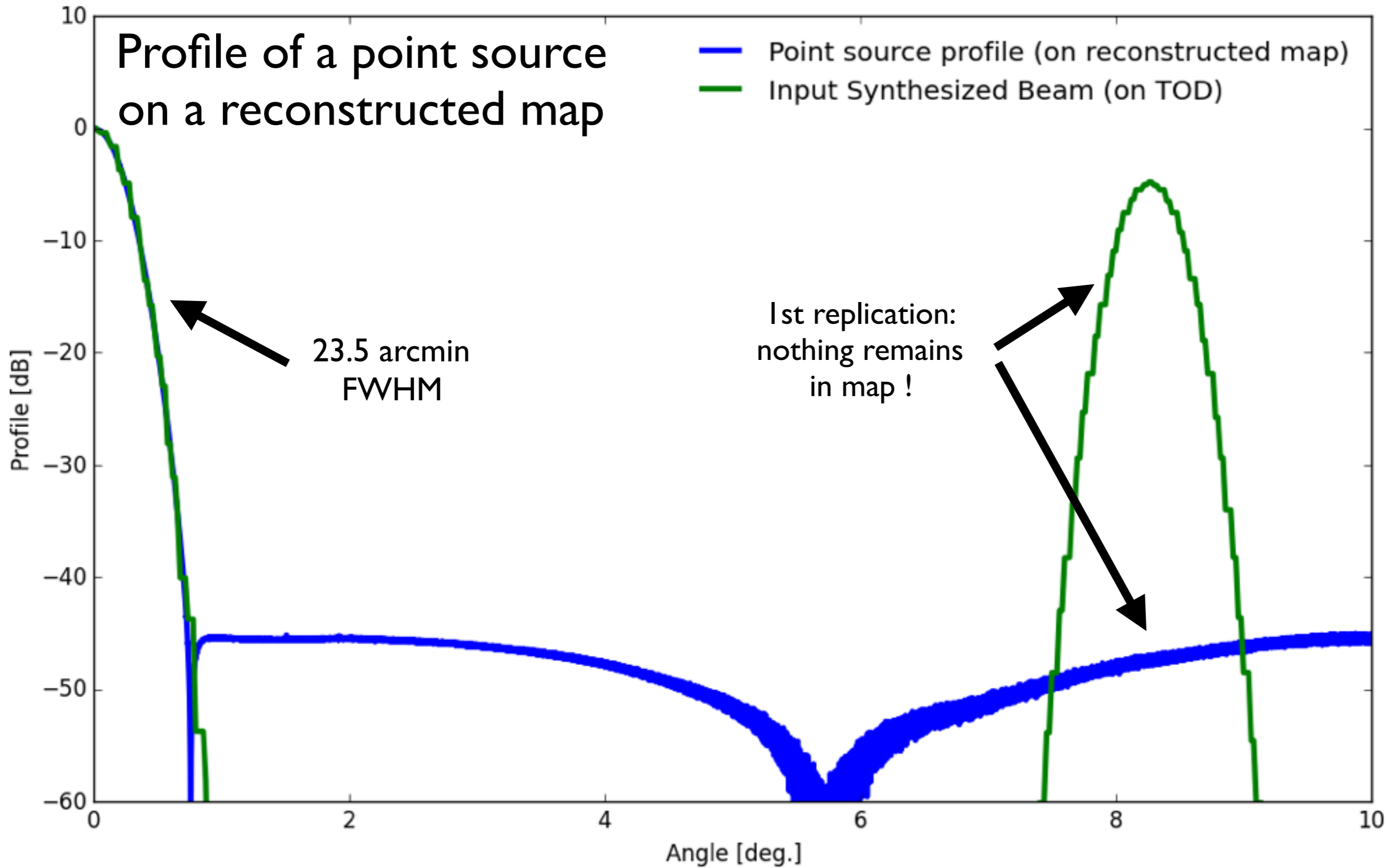
Window: 403.0mm - Nhorns=400



150-220 GHz, 20x20 horns,
13 deg. FWHM, D=1.2 cm

Synthesized beam used to scan
the sky as with an imager

Profile of a point source on a reconstructed map



Systematics: Self-Calibration

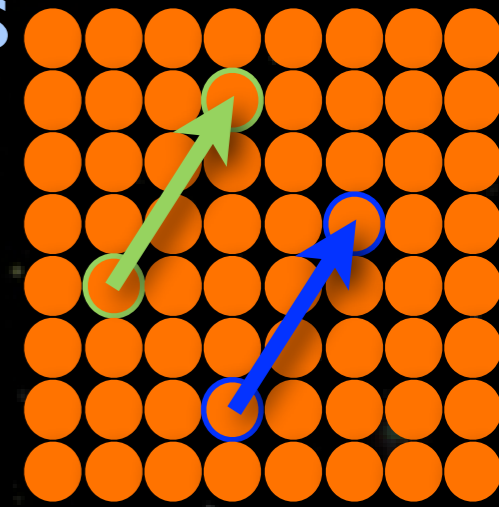
- Unique possibility to handle systematic errors

- ★ Use horn array redundancy to calibrate systematics

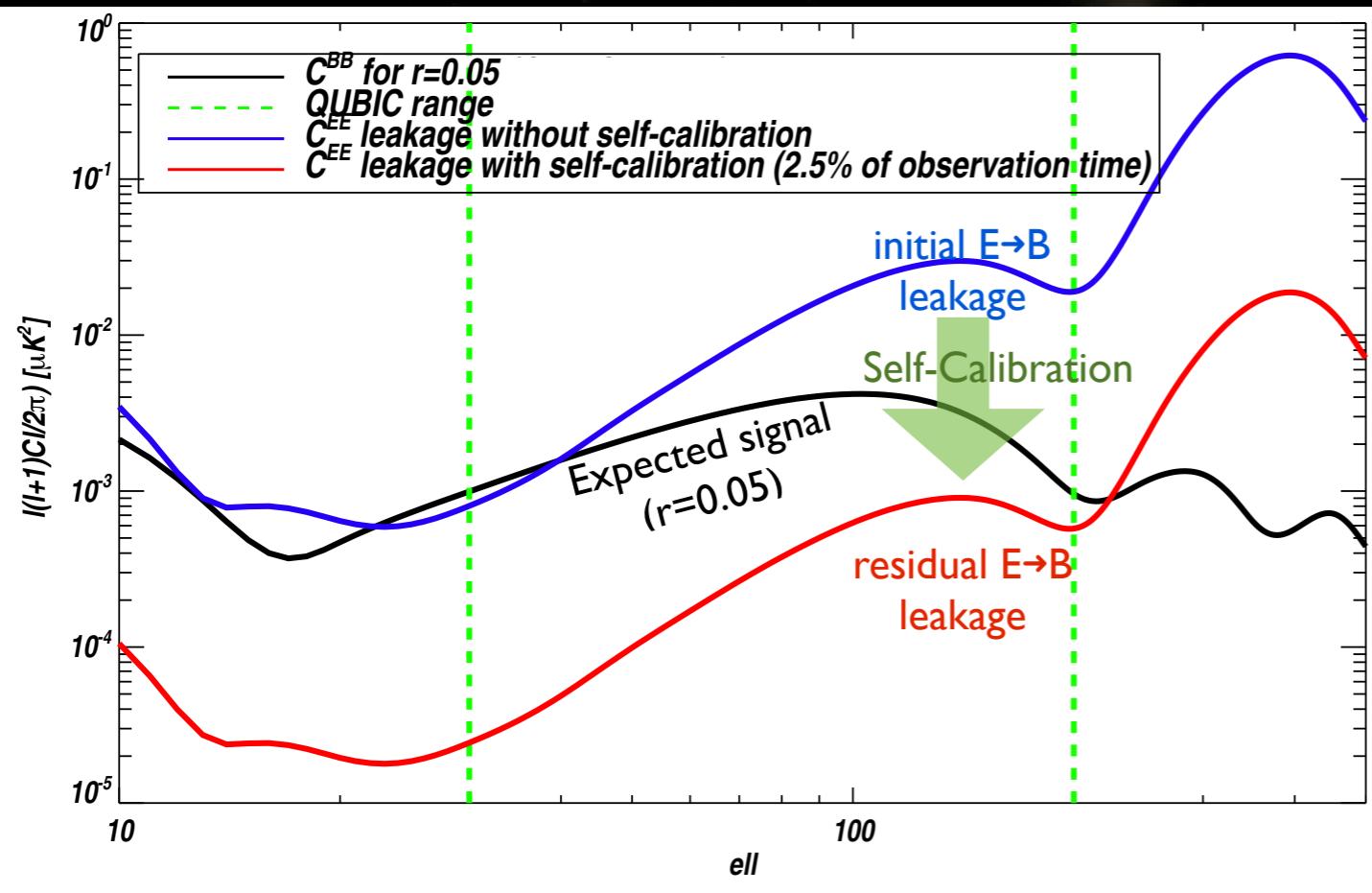
- In a perfect instrument redundant baselines should see the same signal
- Differences due to systematics
- Allow to fit systematics with an external source on the field

- ★ Unique specificity of Bolometric Interferometry !

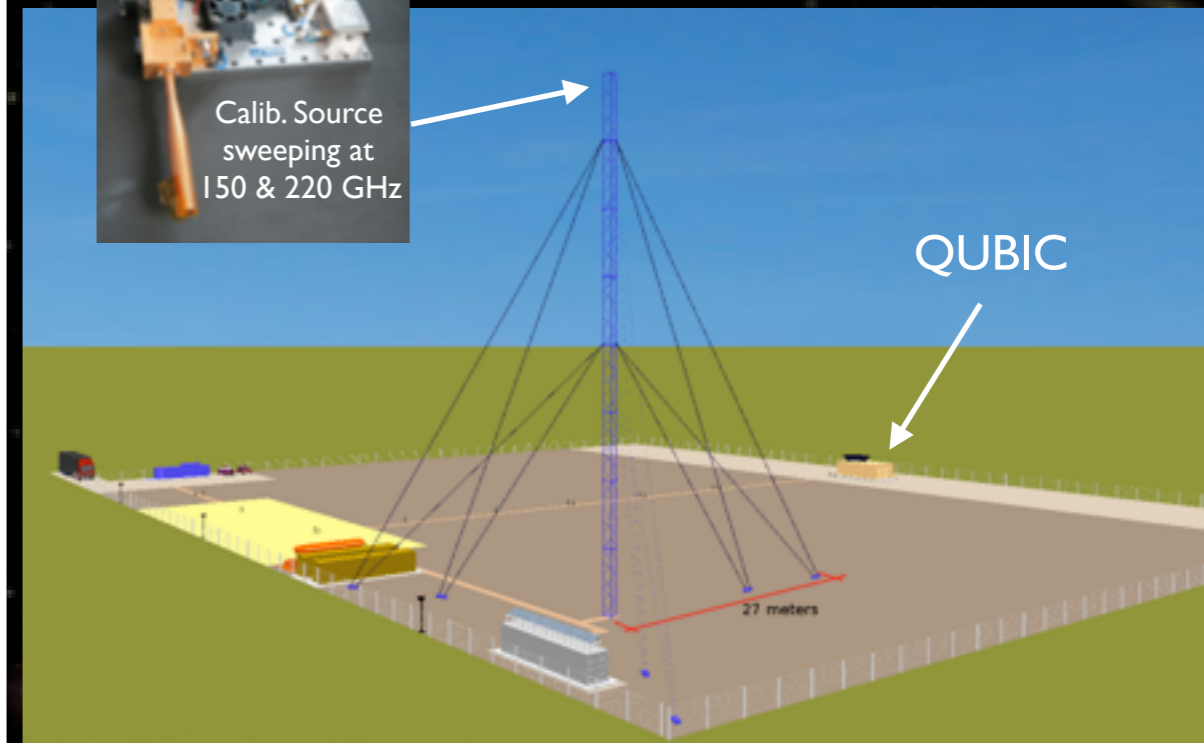
[Bigot-Sazy et al., A&A 2012, arXiv:1209.4905]



Redundant baselines : same Fourier Mode



Calib. Source sweeping at 150 & 220 GHz



QUBIC

QU Bolometric Interferometer for Cosmology

CMB foregrounds for B-mode studies

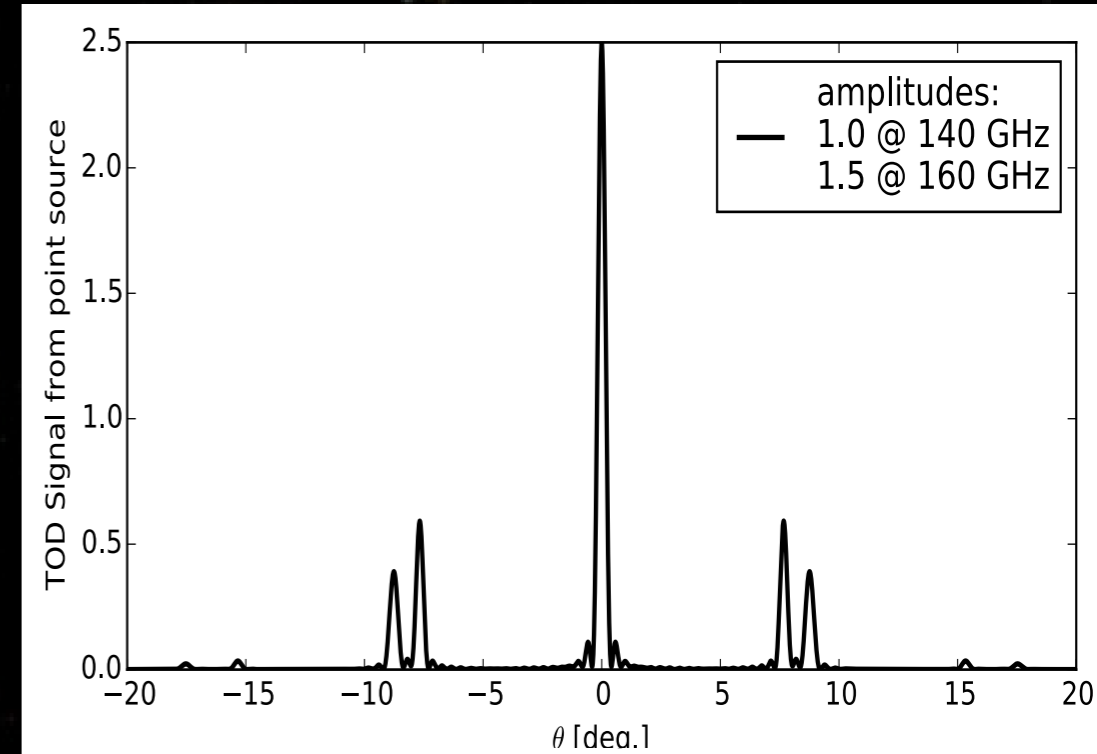
Tenerife, Spain, October 15-18, 2013

J.-Ch. Hamilton

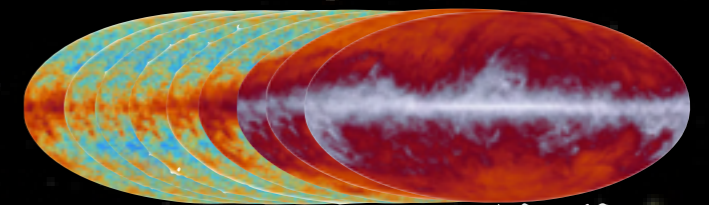


QUBIC is a Synthesized Spectro-Imager

- Synthesized beam:
 - ★ Depends on horns configuration
 - ★ AND on frequency !
 - ex: a point source emitting at 140 and 160 GHz
- There is spatial + frequency information !
- Multi-frequency map-making with the same TOD
 - ★ Spectral resolution $\Delta\nu/\nu \sim 0.05$
 - ★ Shown to be quasi-optimal with simulations
 - ★ article being finalized

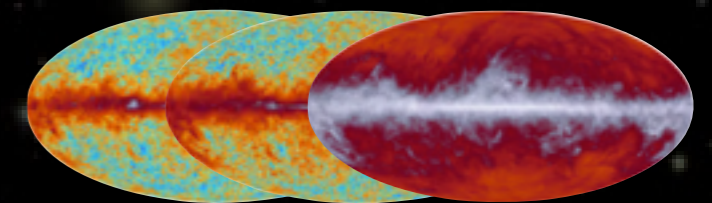


Sky: Continuous frequency maps



$$\text{TOD} = \sum \text{tod}(\nu_i)$$

↓ Map Making



Output: N broadband frequency maps



Data Analysis more complex but richer than with a classical imager

Complex shape of
synthesized beam



Map-making more
complex



CPU...

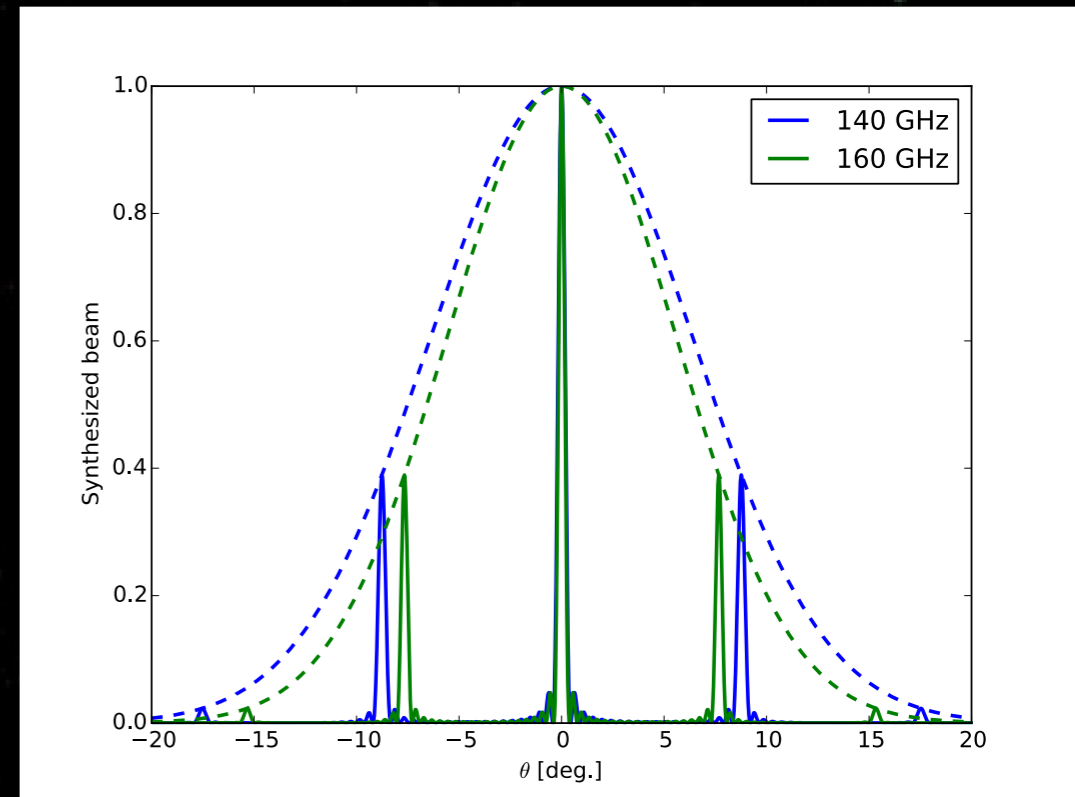
Frequency dependence
of synthesized beam



Spectro-
Imaging

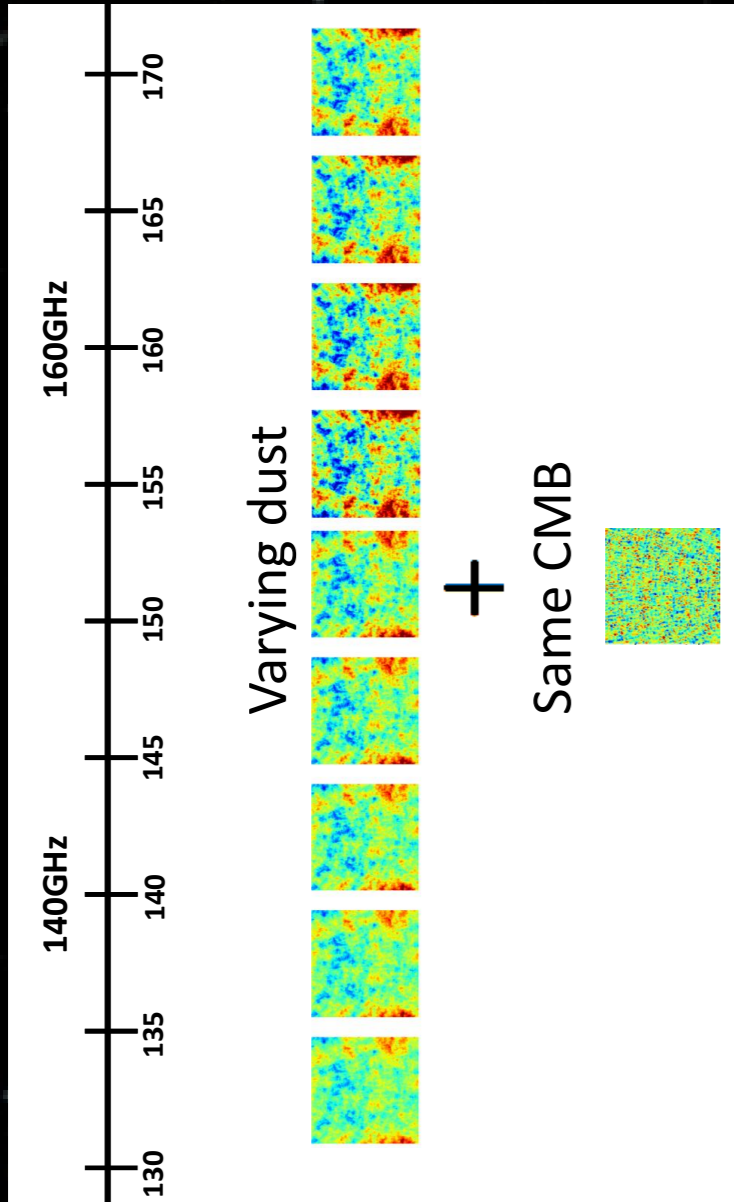


Foregrounds!



Ex: Split one QUBIC band into two sub-bands ($\Delta\nu/\nu \sim 0.125$)

Physical Band: 130-170 GHz



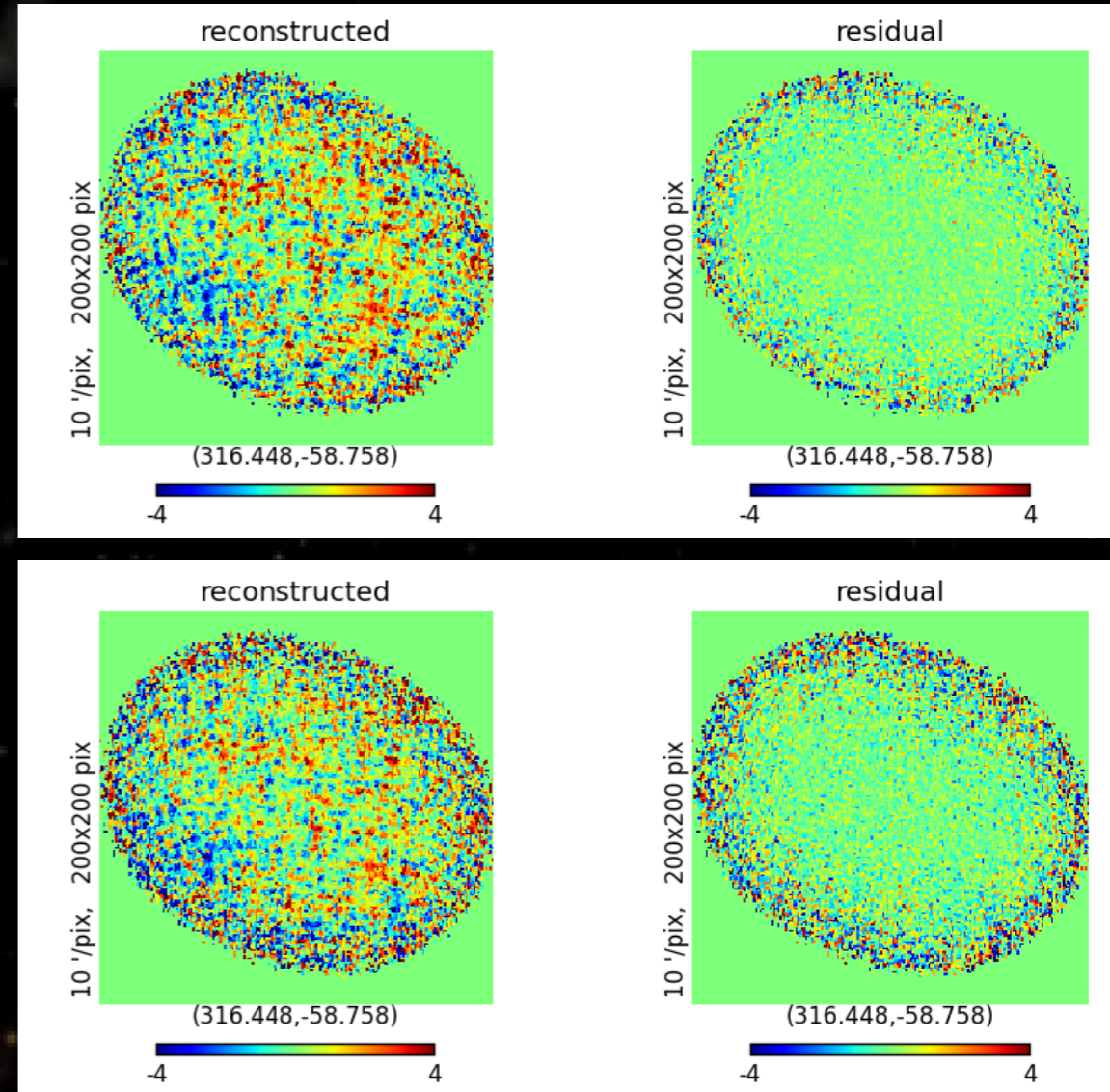
One Single TOD

Synthesized beam

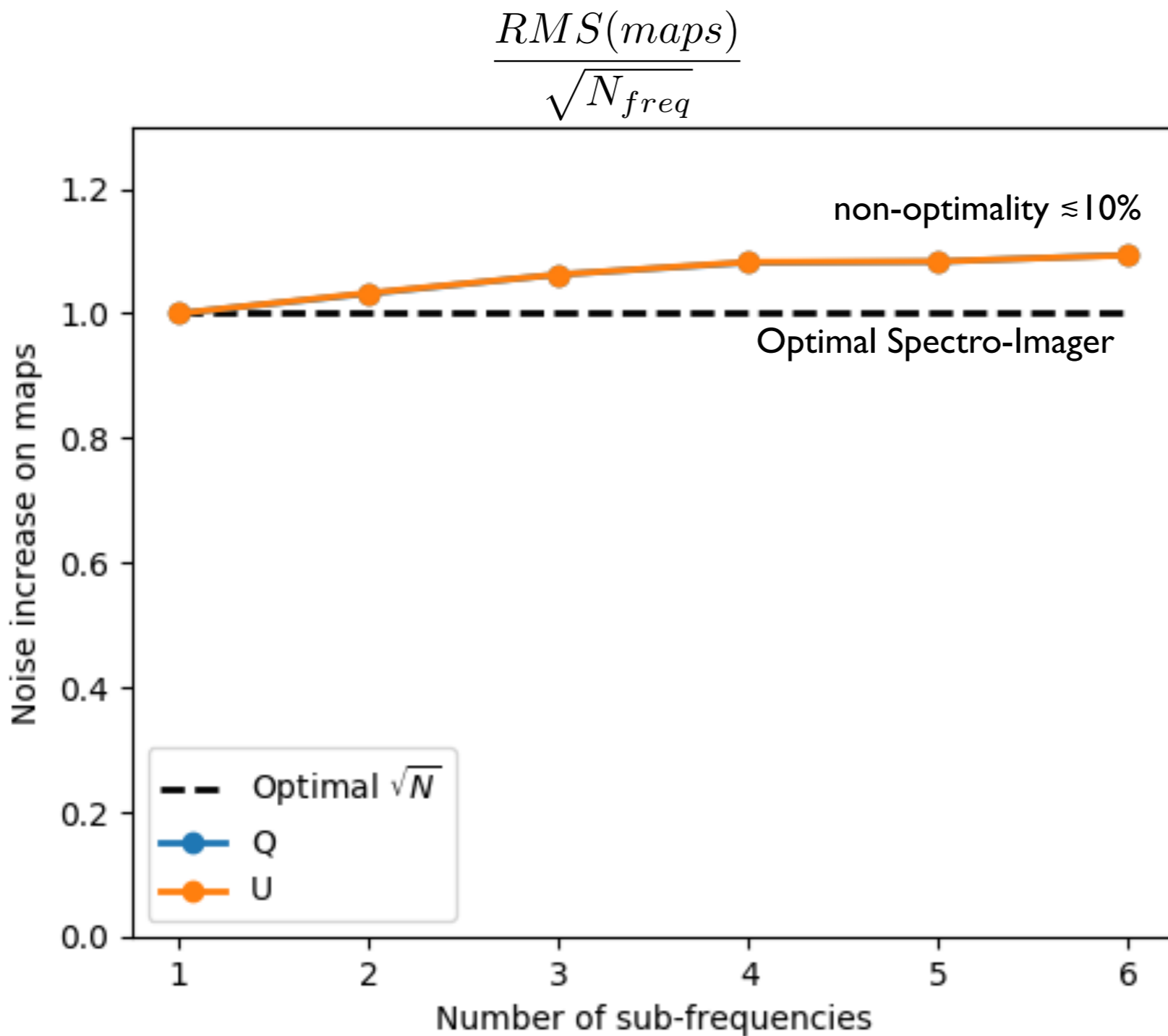
Synthesized beam

150-170 GHz

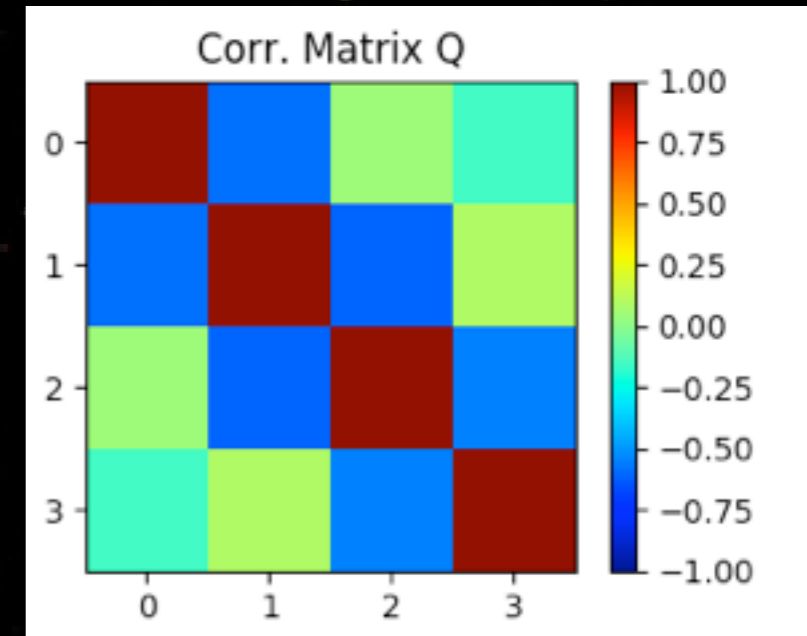
130-150 GHz



Noise penalty for Spectro-Imaging ?



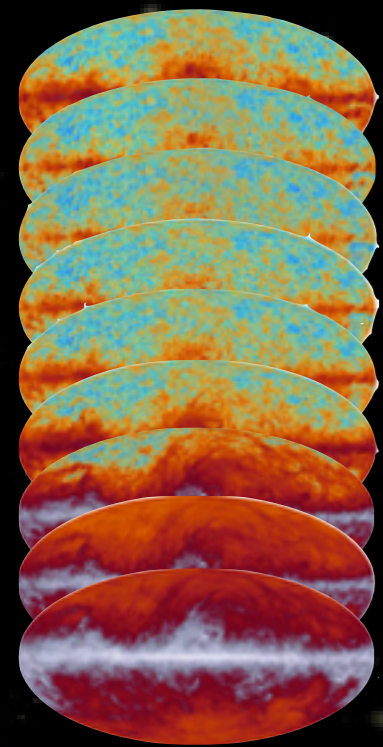
Correlation Matrix for 4 sub-frequencies



Significant gain expected for foreground removal:

- More frequency resolution
- Frequency-localized foreground constraints (less sensitive to extrapolations with simplistic models)

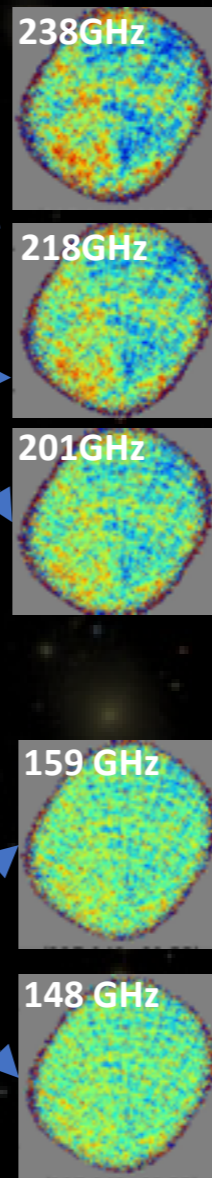
QUBIC Spectro-Imaging



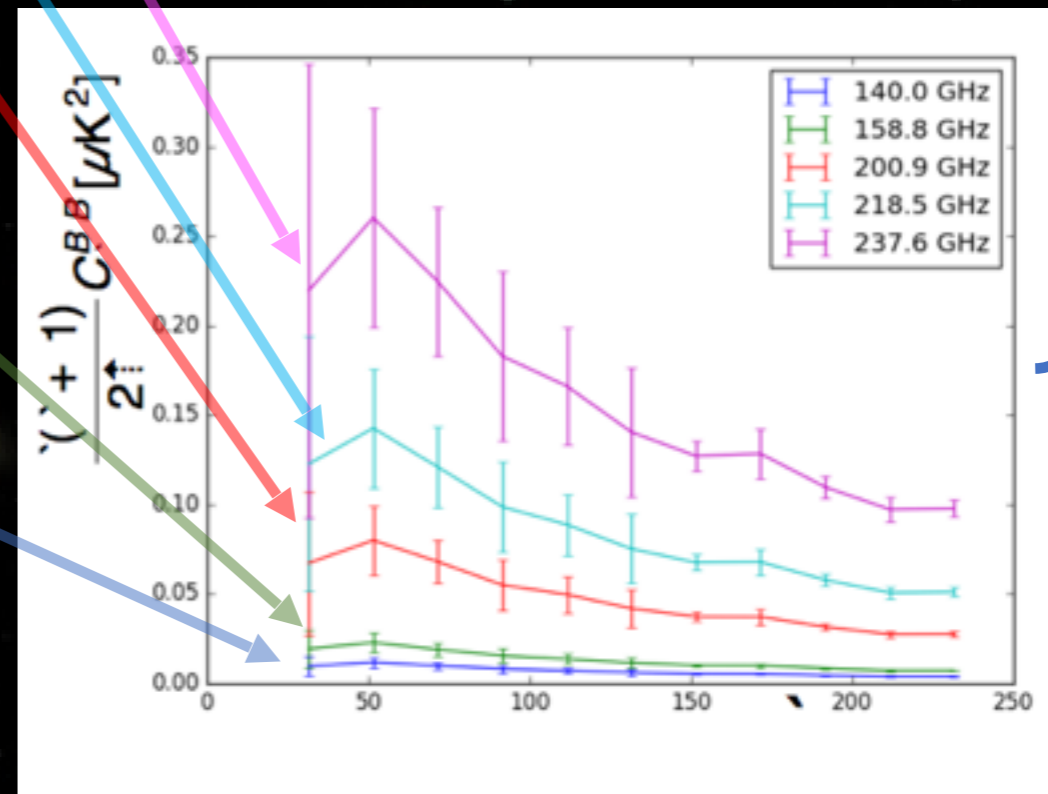
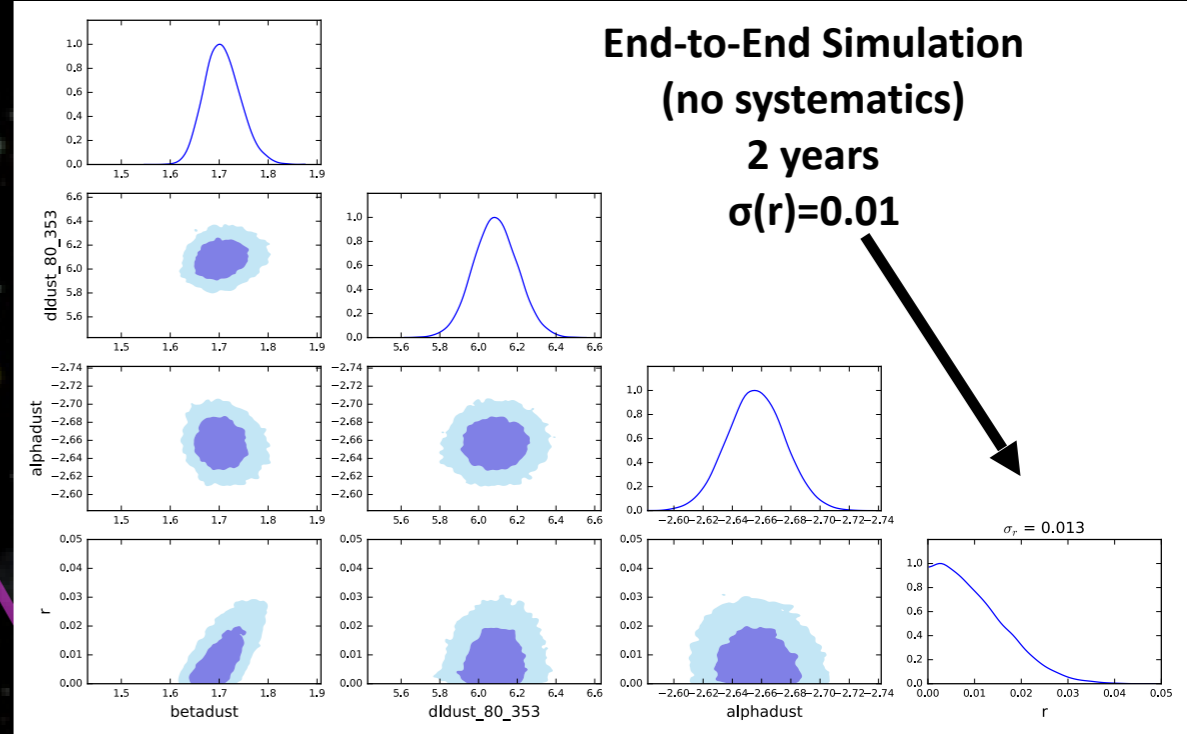
Sky:
« Infinite # bands »



Instrument:
2 wide bands



Data Analysis:
5 narrow bands



- => Increased Spectral Resolution
- => Dust subtraction
- => More complex models can be constrained
[specific index varying simulations being done]



QUBIC
QU Bolometric Interferometer for Cosmology

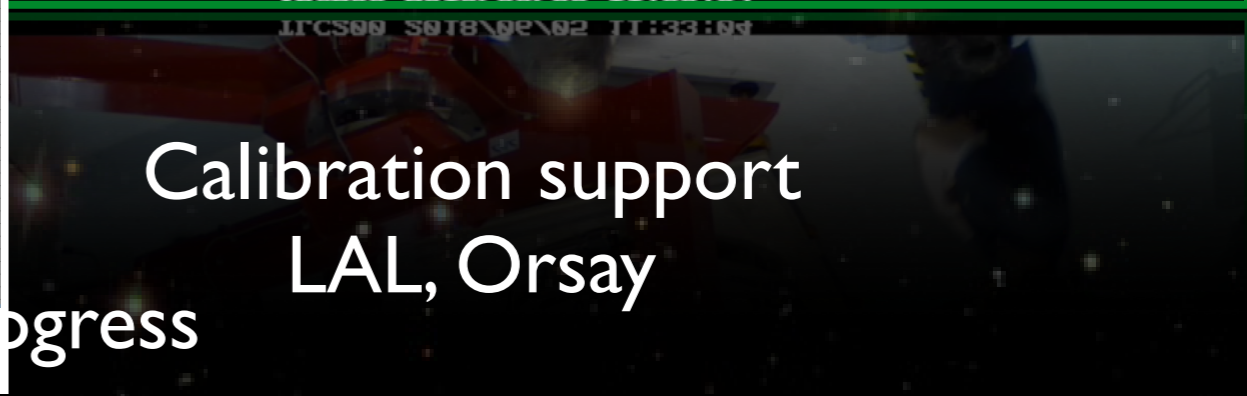
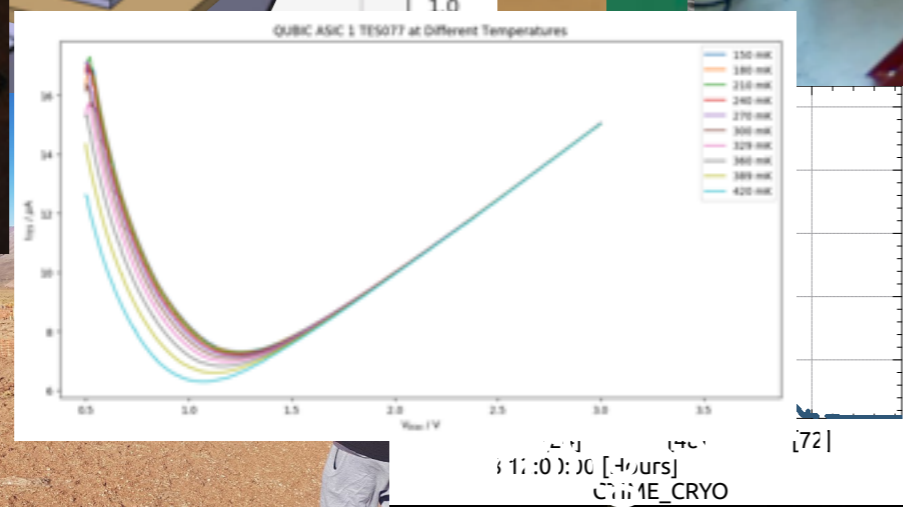
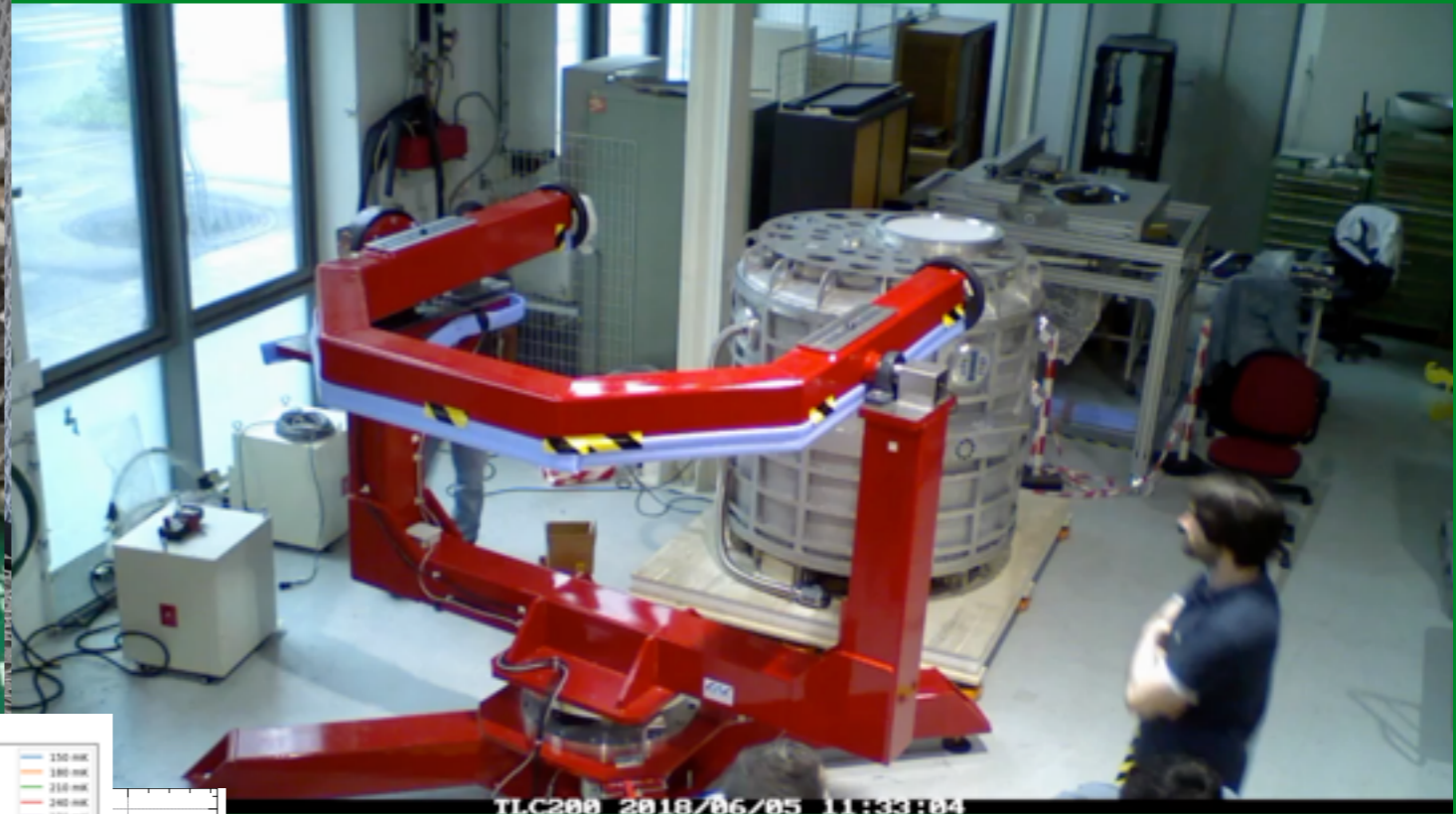
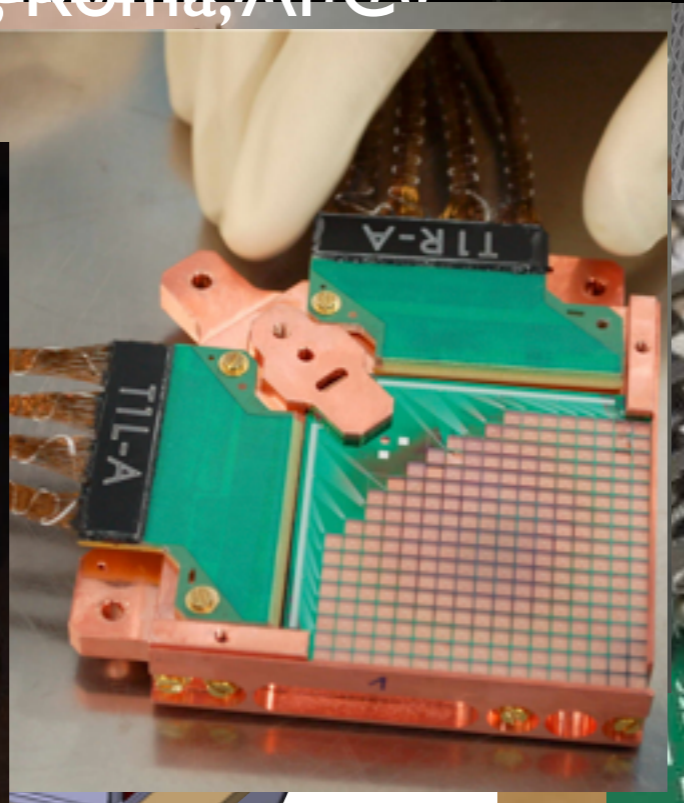
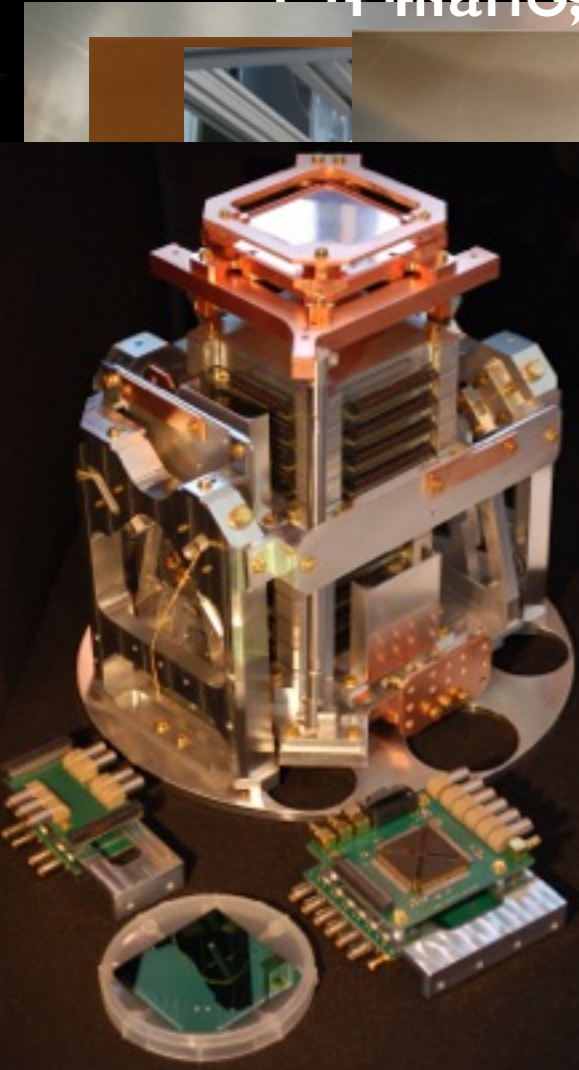
CMB foregrounds for B-mode studies
Tenerife, Spain, October 15-18, 2013

J.-Ch. Hamilton



QUBIC Integration and sub-systems

Site: Desierto de Atacama, Chile
 Site: Dome A, Antarctica
 Site: Plateau Station, Antarctica
 Site: Cerro Paranal, Chile
 Site: Cerro Chajnantor, Chile
 Site: Cerro Tololo, Chile
 Site: Cerro Gemini, Chile
 Site: Cerro Mirnitskiy, Chile
 Site: Cerro Silla, Chile
 Site: Cerro Tololo, Chile
 Site: Cerro Tololo, Chile
 Site: Cerro Tololo, Chile
 Site: Cerro Tololo, Chile



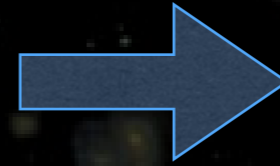
1:128 SQUIDS+ASIC Mux
 2048 TES Bolometers
 (256 for TD)

Calibration support
 LAL, Orsay

QUBIC Deployment Plan

2018 : at APC

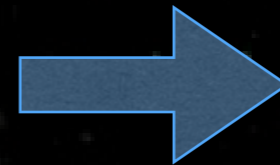
- Integration and testing on the way
- Technological Demonstrator (reduced QUBIC)
 - 1/4 focal plane, 64 horns, small mirrors
- Followed by: Upgrade to full size mirrors and 400 horns



In-Lab demonstration of Bolometric Interferometry

2019 : Argentina

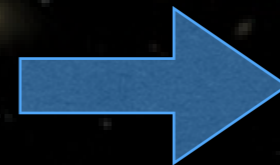
- First Half 2019: Installation on site
- First Light Mid-2018 with ¼ focal plane



On-Sky demonstration of Bolometric Interferometry

2019 : Argentina

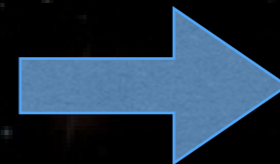
- Upgrade to QUBIC 1st module (2 focal planes 150 and 220 GHz)
- Data taking: 2-3 years $\sigma(r)=0.01$



Stage III
 $\sigma(r) = 0.01$

2020-... : QUBIC evolves towards Stage-IV

- European extension of the collaboration
- Improved designs being investigated: eg/ BI tube in CMB-S4
- Excellent quality site open to development



Evolution to Stage IV
 $\sigma(r) = 0.001$



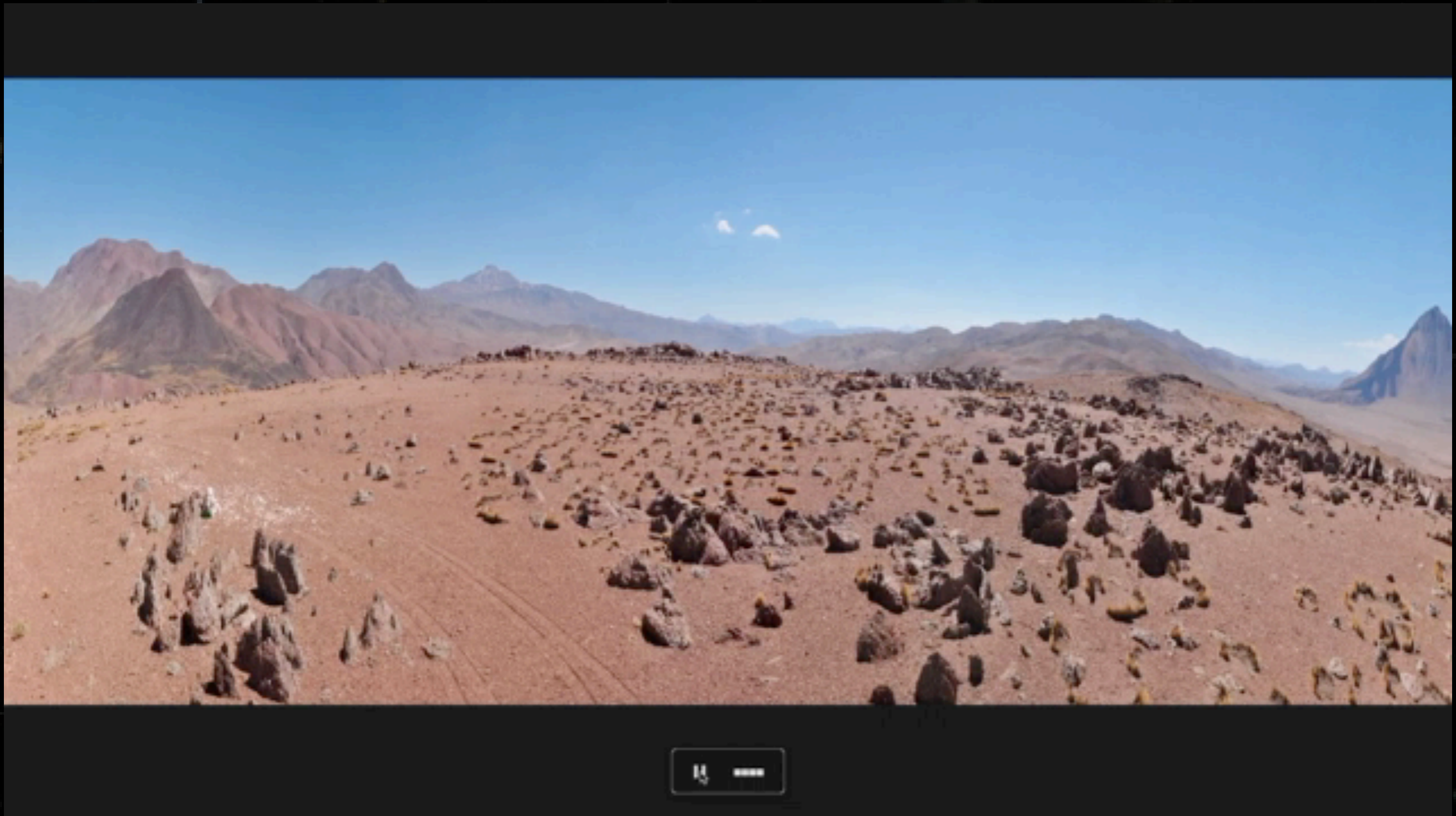
Summary

- QUBIC is a novel instrumental concept
 - ★ First Bolometric Interferometer
 - ★ Dedicated to CMB polarimetry and inflationary physics
 - ★ High sensitivity with ~ 2000 TES bolometers
 - ★ Optimized to handle systematics:
 - *Self Calibration allowed by observing individual fringe patterns (Unique to QUBIC)*
 - ★ Spectro-Imaging with two physical bands (150 / 220 GHz) and 5-10 sub-bands:
 - *Foregrounds contamination control and removal with up to 10 bands (unique to QUBIC)*
 - ★ Target :
 - *First module (150-220 GHz): $\sigma(r)=0.01$ (incl. dust)*
 - *Stage IV evolution of QUBIC $\sigma(r)=0.01$ hopefully through a wider European collaboration + CMB-S4 tube(s)*
- QUBIC deployment is on the way:
 - ★ TD Integration ongoing at APC
 - ★ Calibration measurements up to 1st term 2019
 - ★ First light in Argentina mid-2019
 - ★ Upgrade to First Instrument in 2019

● Welcome to jump-in anytime !!!



Thank you



Exciting times ahead !!!



QUBIC

QU Bolometric Interferometer for Cosmology

18

CMB foregrounds for B-mode studies

Tenerife, Spain, October 15-18, 2013

J.-Ch. Hamilton

