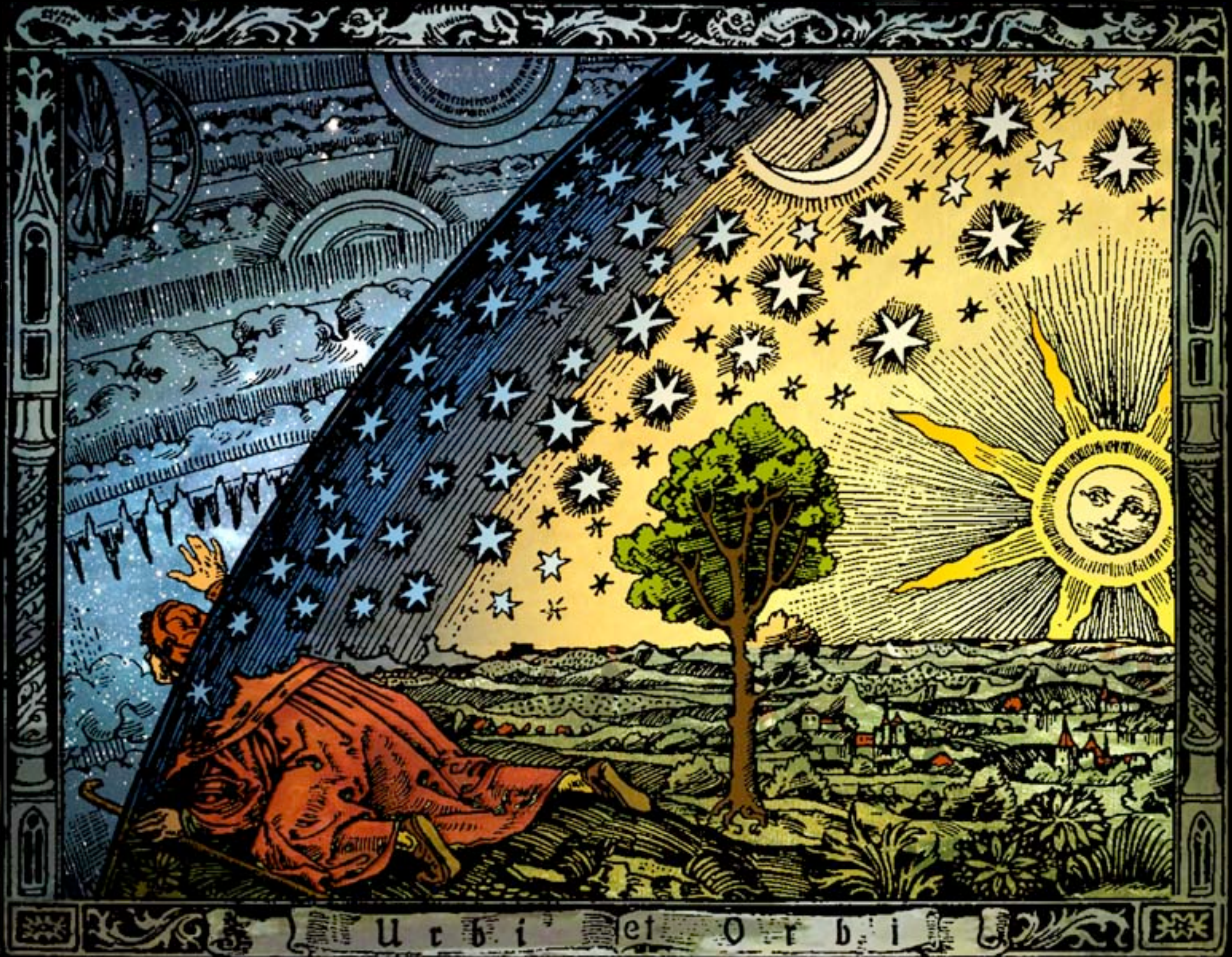
Exploring the primordial Universe with QUBIC

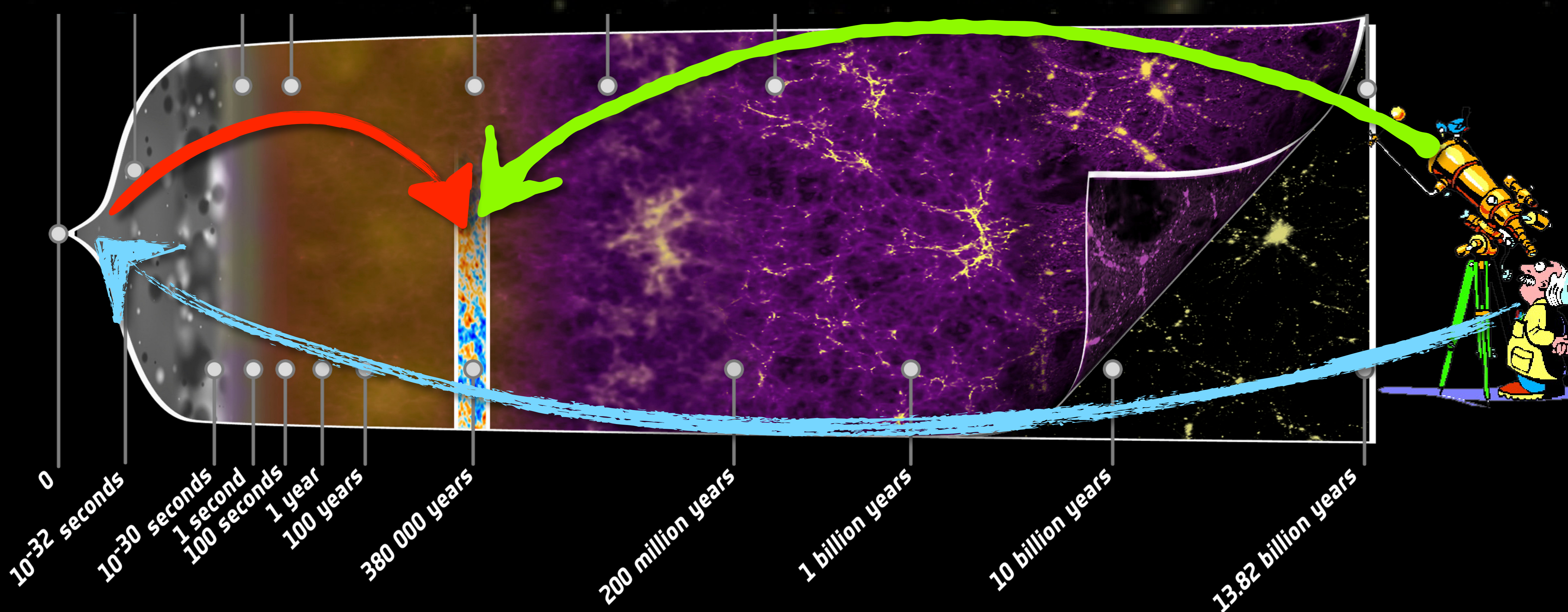
the Q U Bolometric Interferometer for Cosmology



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

See P. de Bernardis talk yesterday for a detailed review

CMB B-modes



Observing the CMB B-modes polarization gives access to the Primordial Universe physics (inflation epoch)

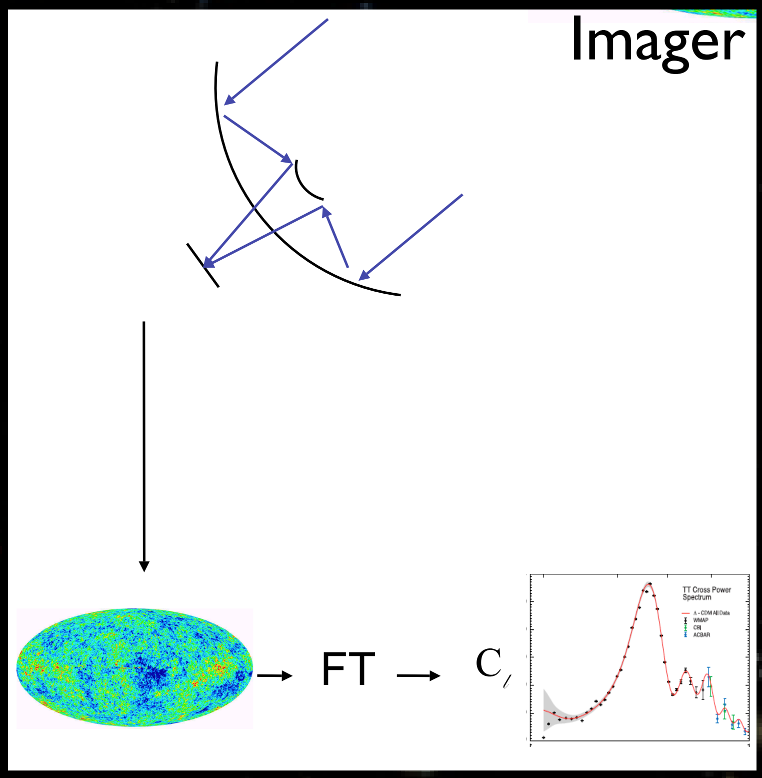
Difficulties:

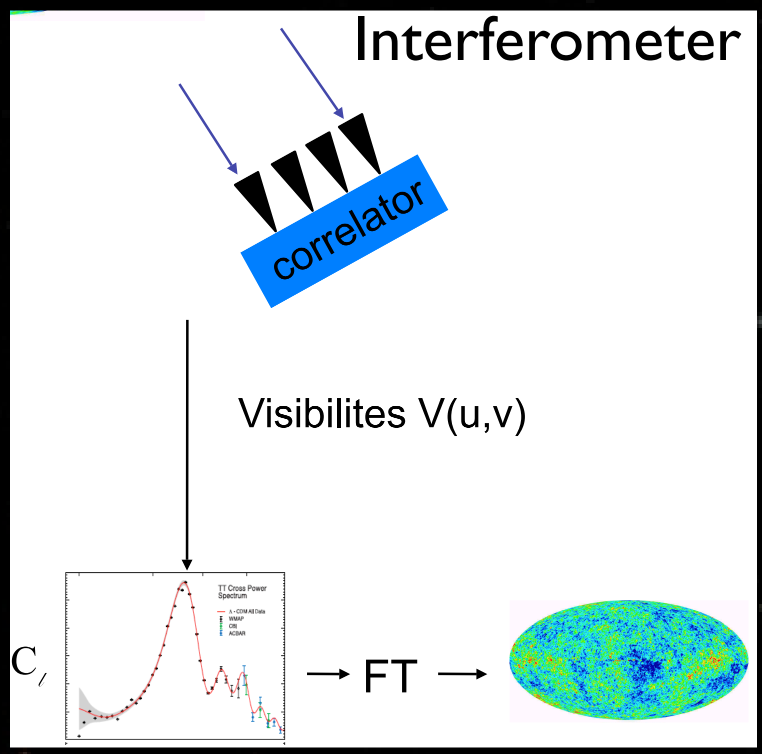
- Sensitivity (few nK signal)
- Instrumental Systematics (I,Q,U leakage)
- Foregrounds (Polarized dust, …)

Possible instruments

- **Imagers:**
  - ★ With bolometers (or MKIDs…):
    - Wide band & Low noise
  - ★ Coherent detectors
    - Well mastered, not too noisy from the ground, great at low-frequency
  - ★ Usually significant cross-pol & ground-pickup from telescope
- **Interferometers:**
  - ★ Long history in CMB
    - CMB anisotropies in the late 90s (CAT: 1st detection of subdegrees anisotropies, VSA)
    - CMB polarization 1st detection (DASI, CBI)
  - ★ Technology used so far
    - Antennas + HEMTs : higher noise (but reasonable from ground)
    - Correlators : hard to scale to large #channels
  - ★ Clean systematics:
    - No telescope (lower ground-pickup & cross-polarization)
    - Angular resolution set by receivers geometry (well known)
- **Bolometric Interferometry ?**
  - ➡ QUBIC

From P. Timbie





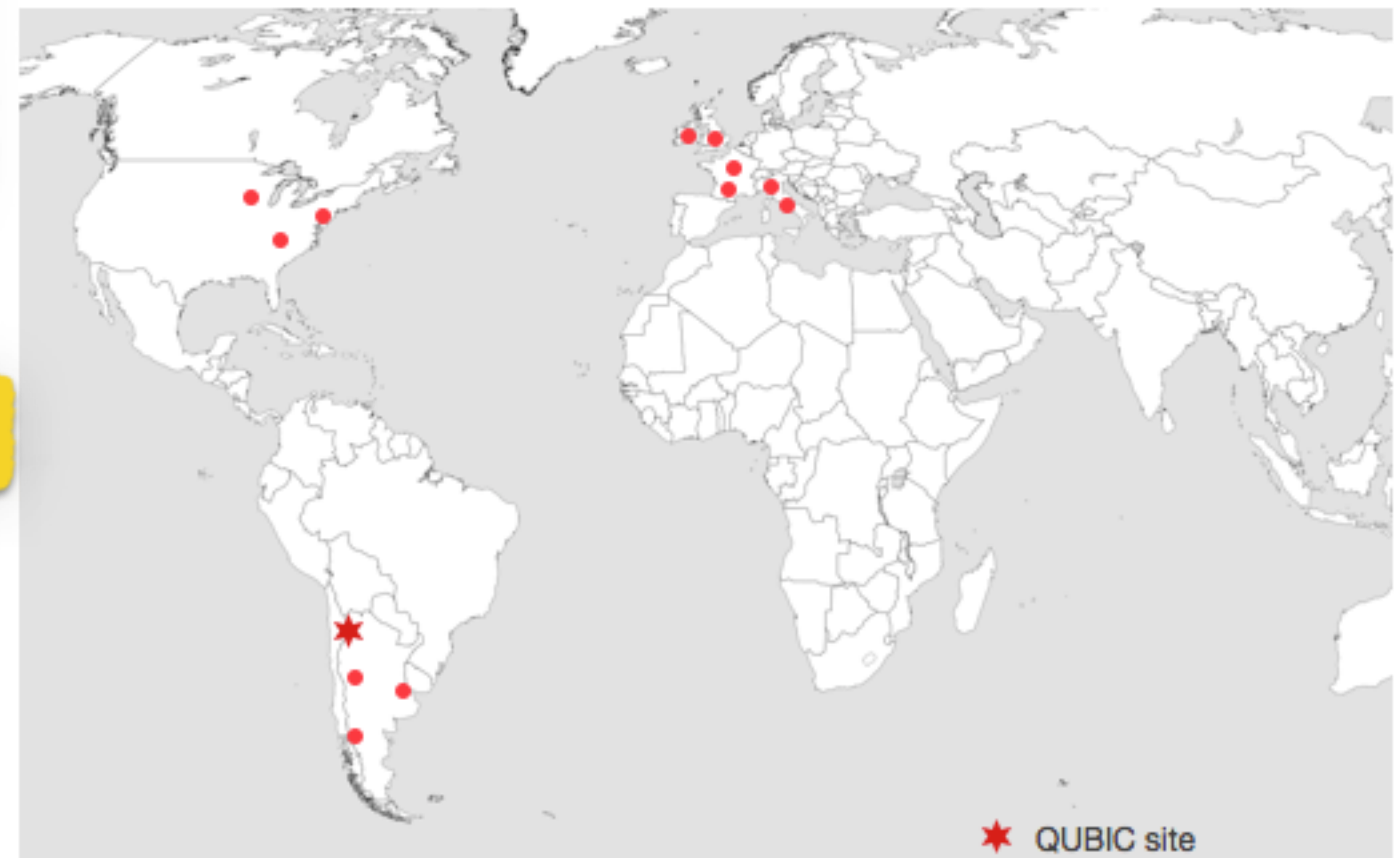
QUBIC

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 Joined



Primordial B-modes with QUBIC

Very weak signal

- **Focal Plane:**
  - 2048 TES with NEP ~ $4x10^{-17}$ $W.Hz^{-1/2}$
  - 128:1 SQUIDs+ASIC Mux Readout
  - **End-To-End Sims. show σ(r)=0.01 with 2 years**

Instrumental systematics

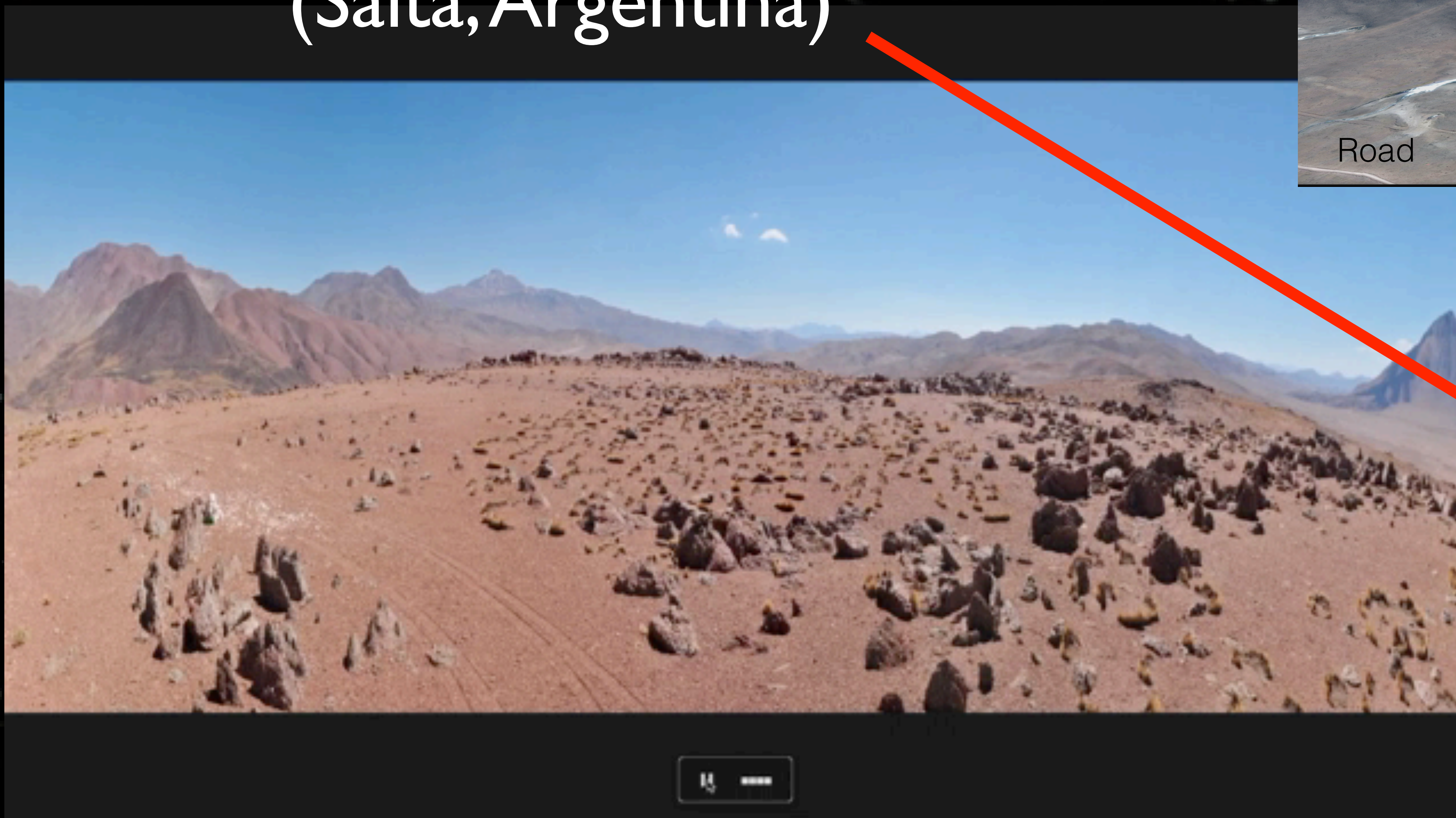
- **Cryogenic Optics after HWP and Polarizer + Full power detectors**
  - ➢ Instrumental Polarization has no effect

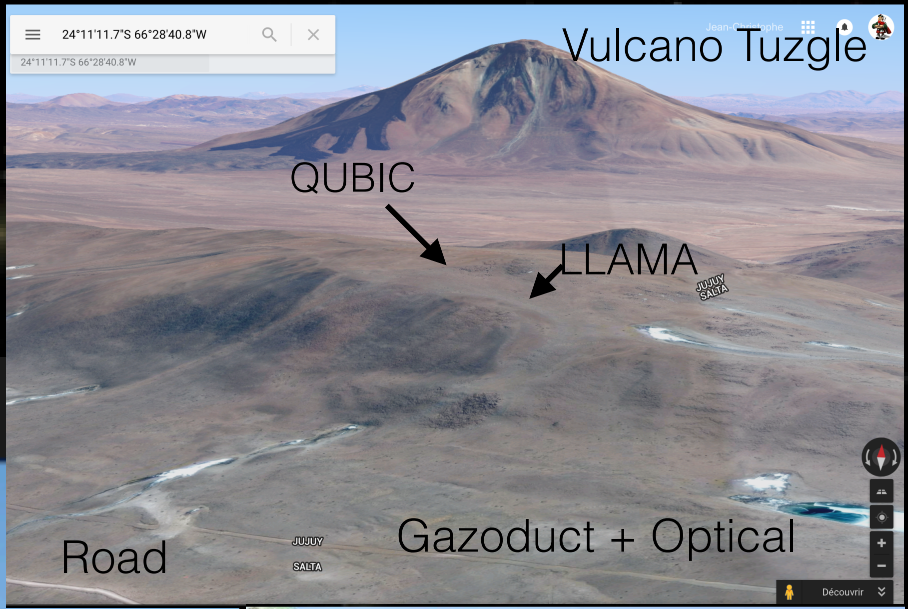
- **400 elements Interferometer**
  - Synthesized Imaging (well controlled beam) – angular resolution 23.5 arcmin
  - **Self-Calibration** using switches + active source

Polarized foregrounds

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

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)

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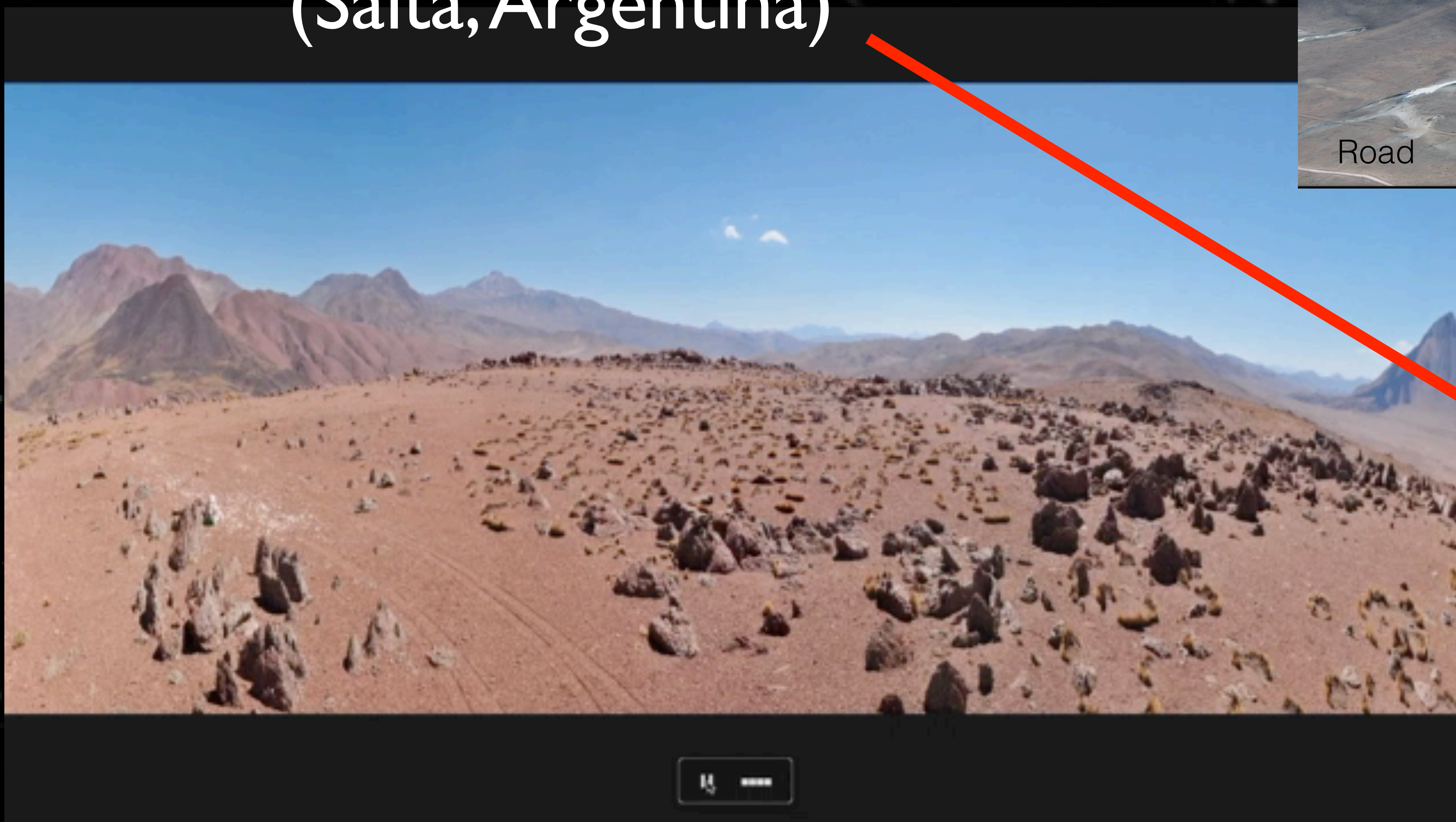

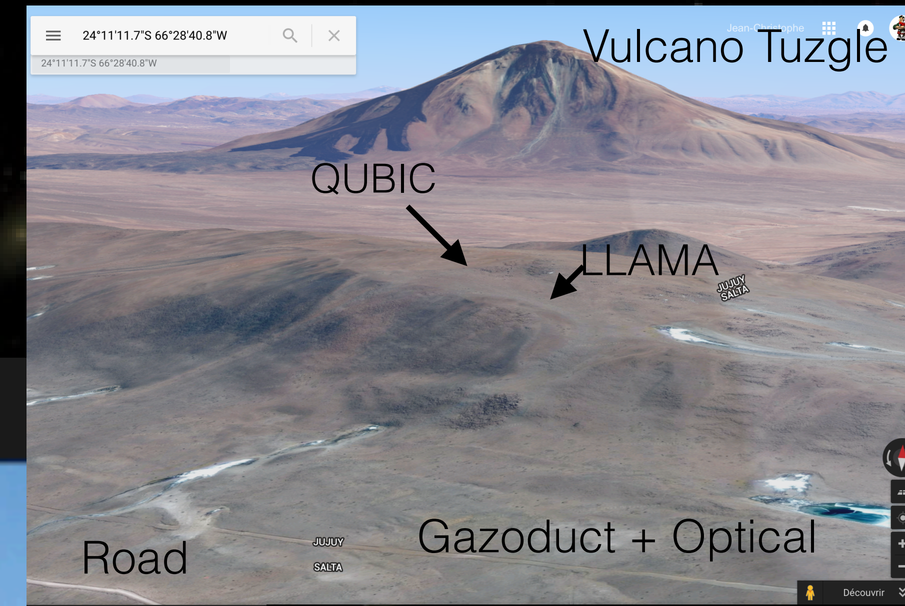

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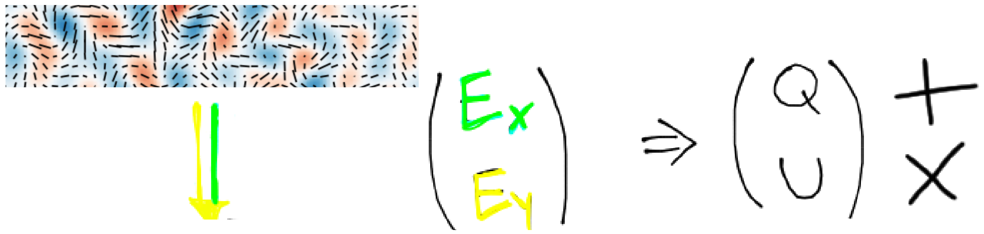
QUBIC concept: Quasi optical correlator



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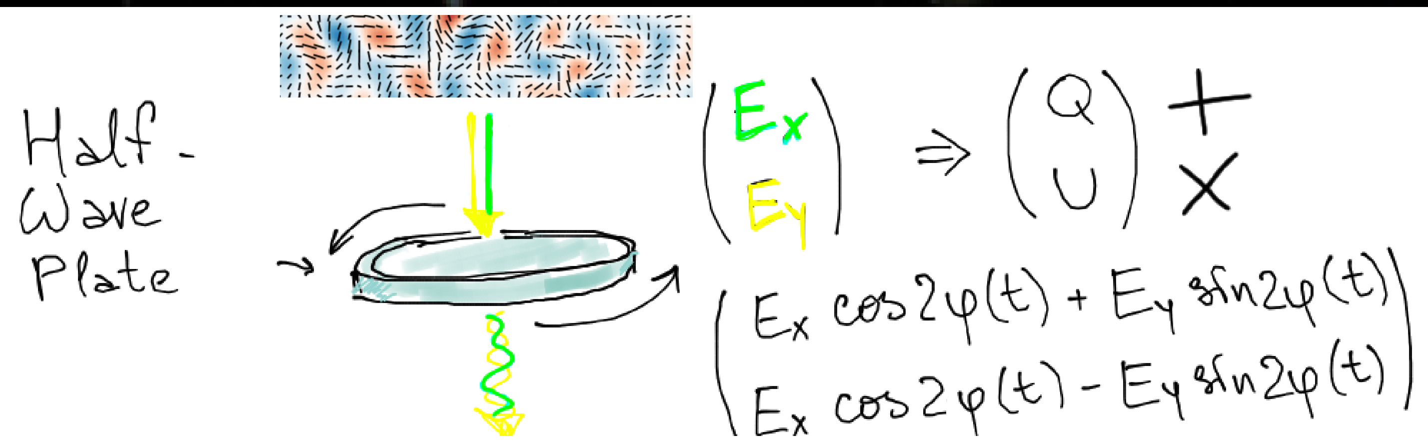

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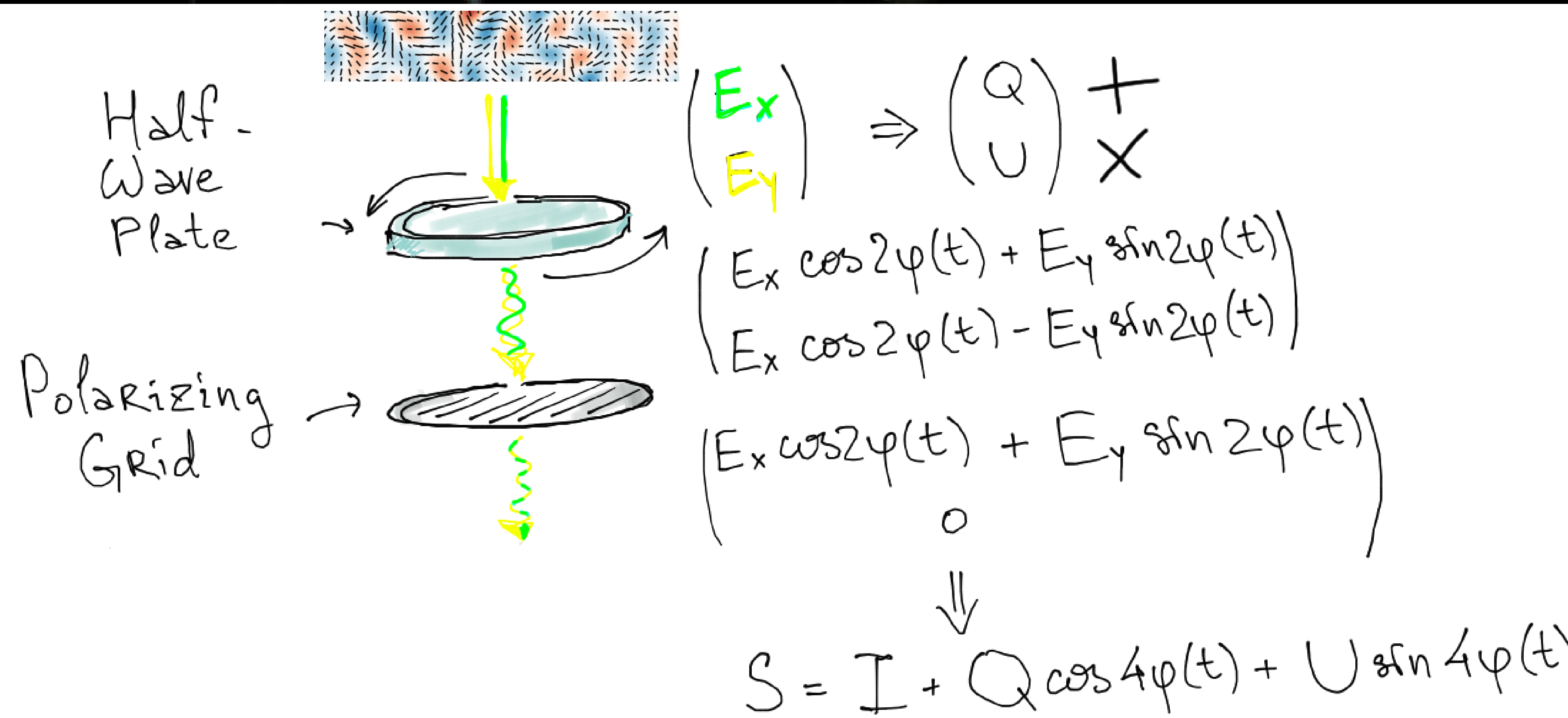

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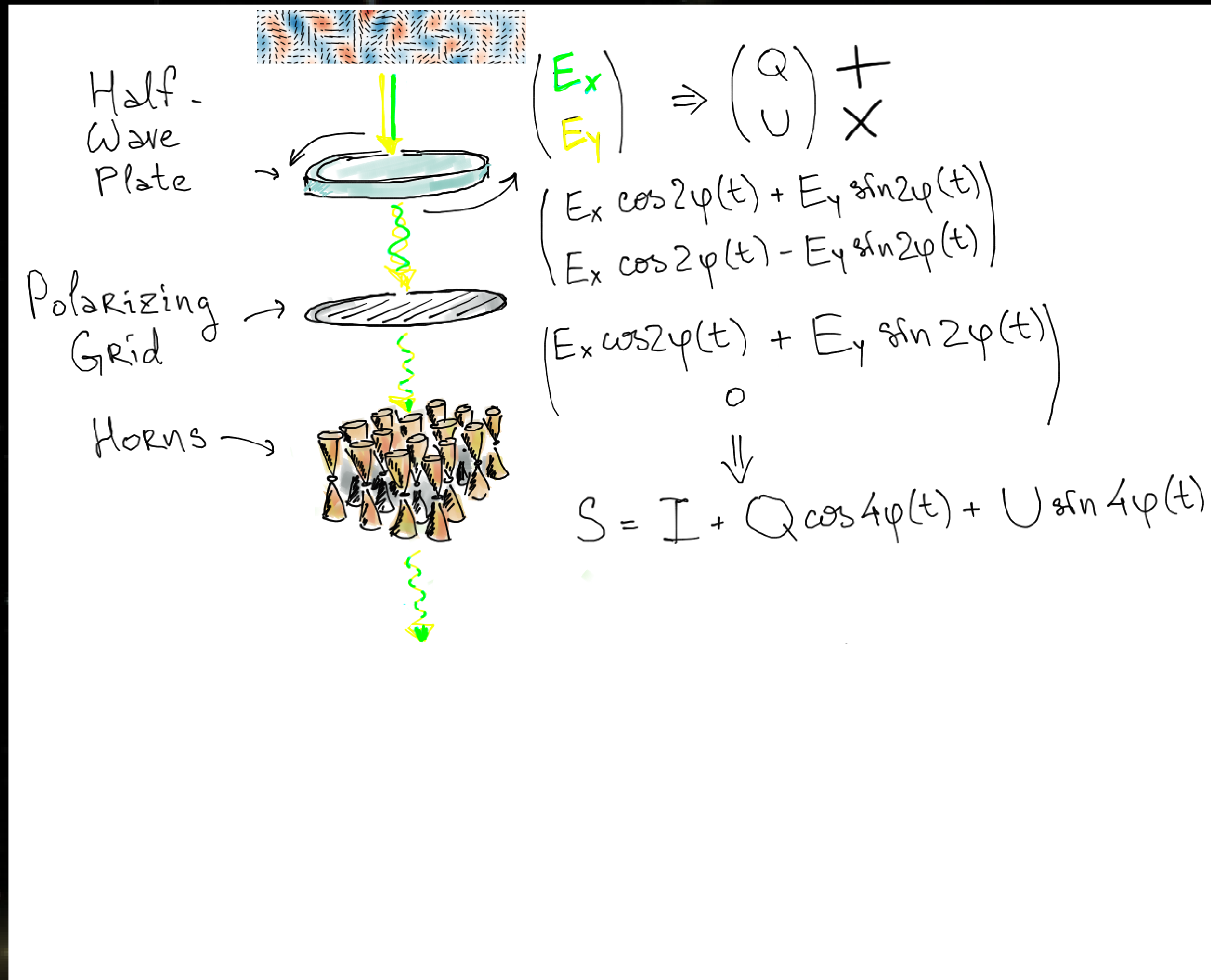

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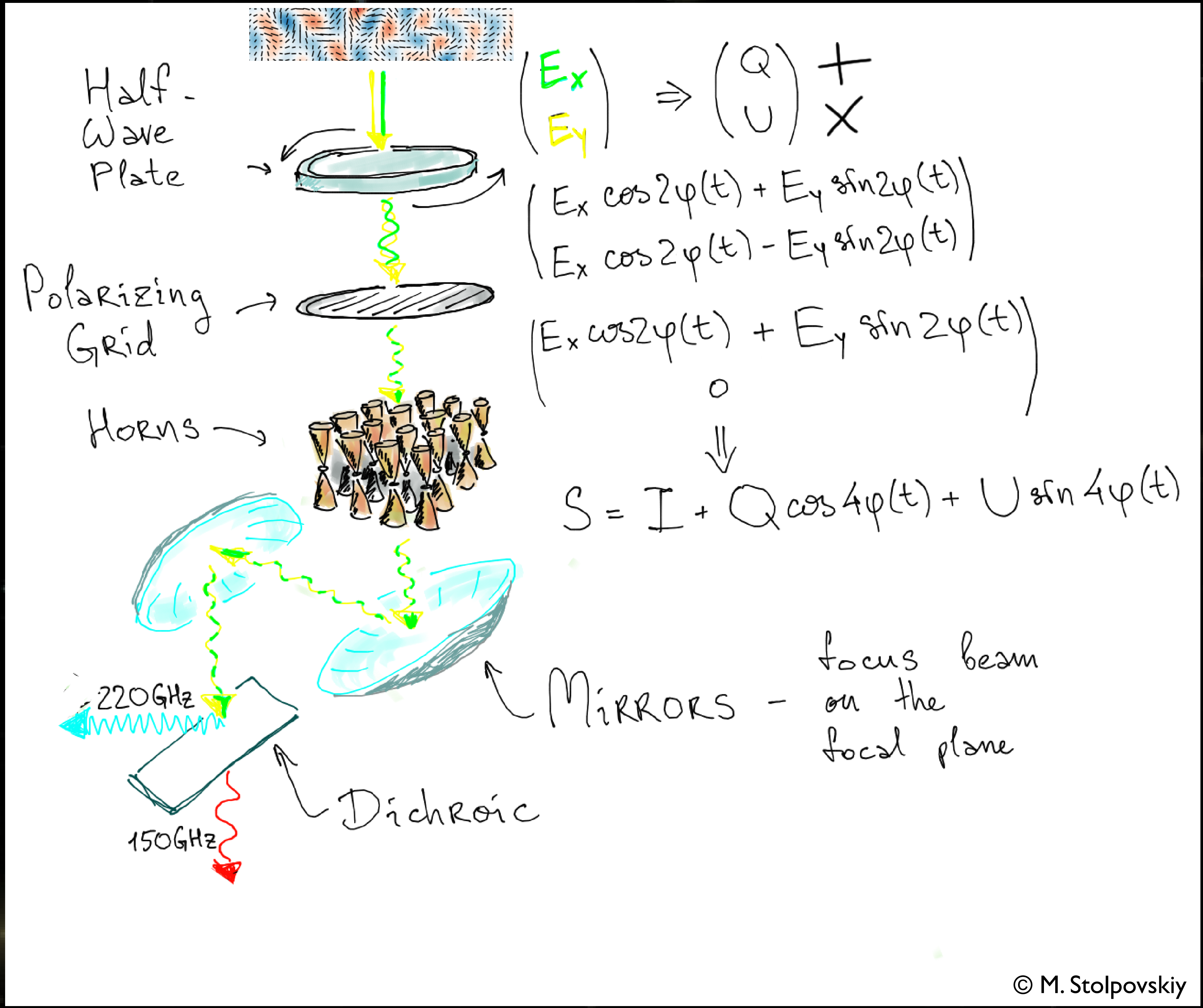

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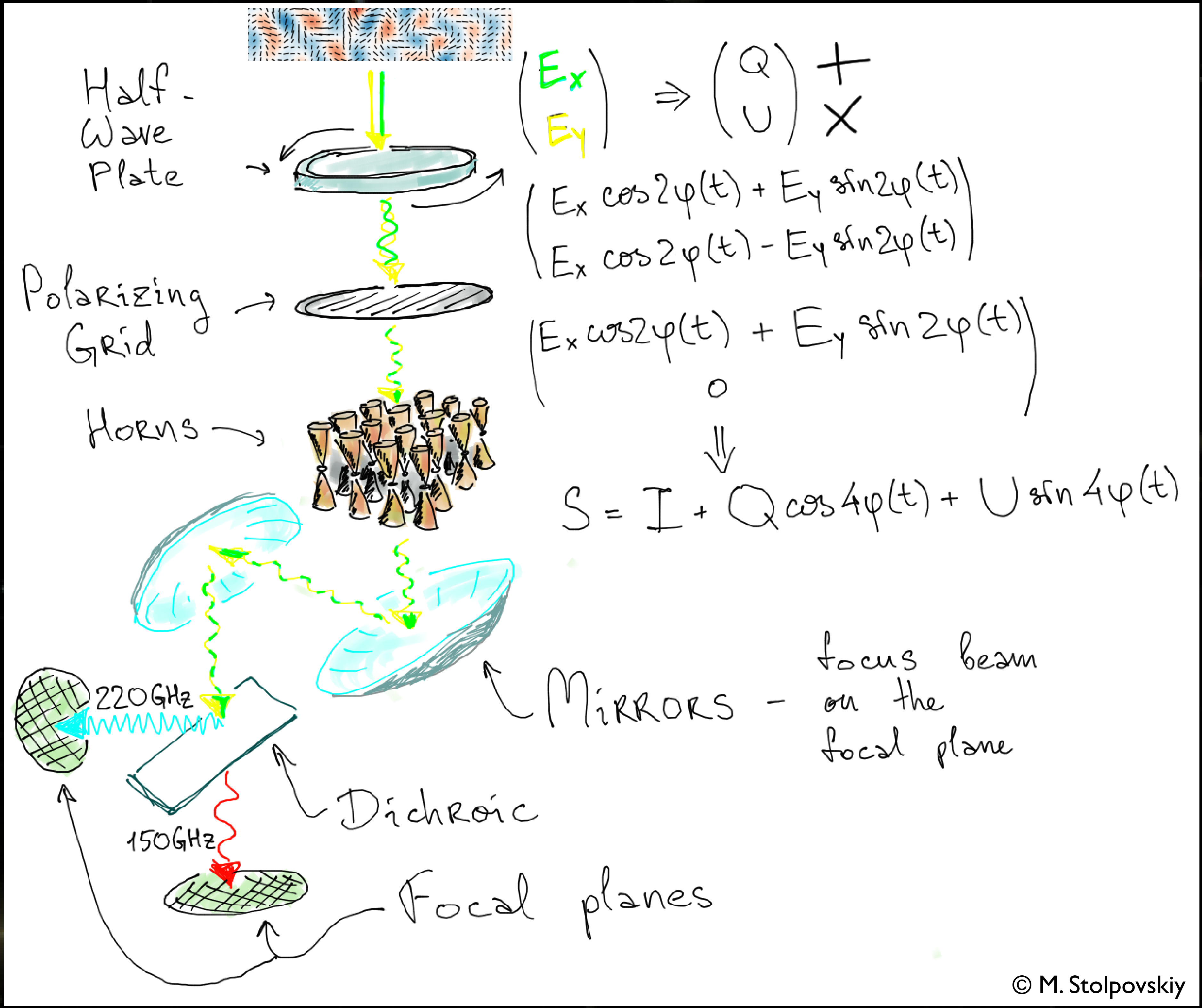

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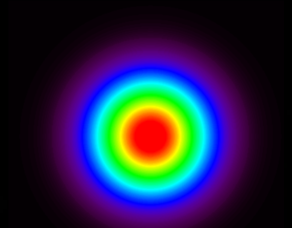
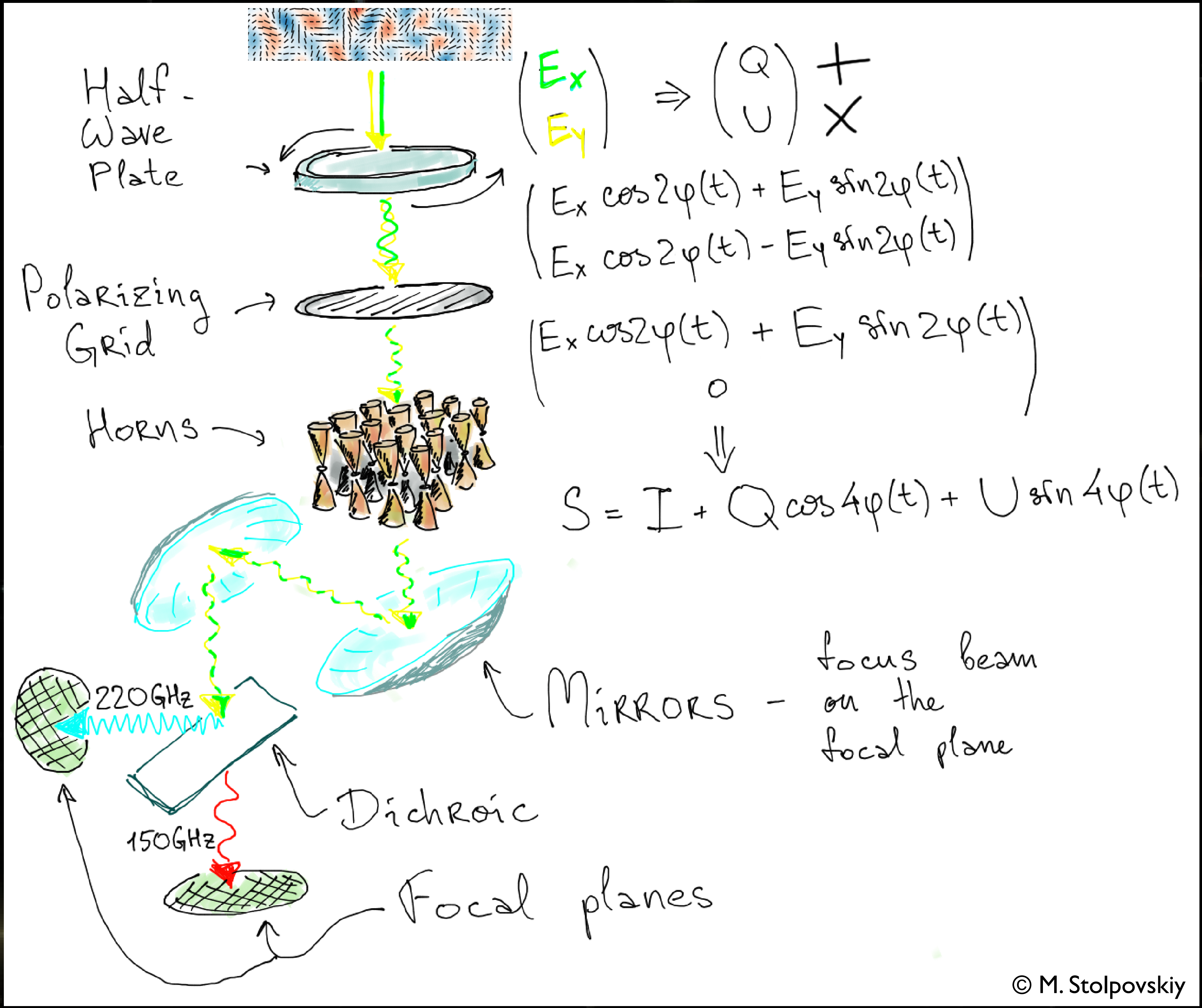

1 horn open



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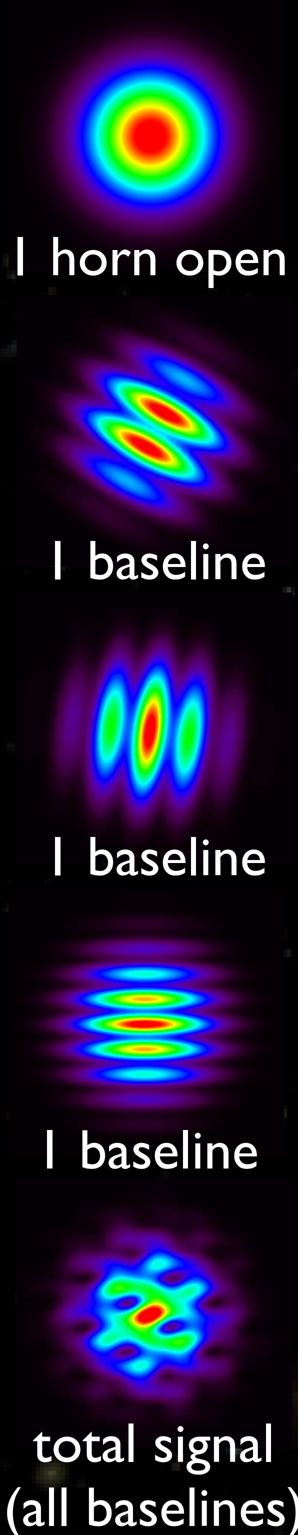
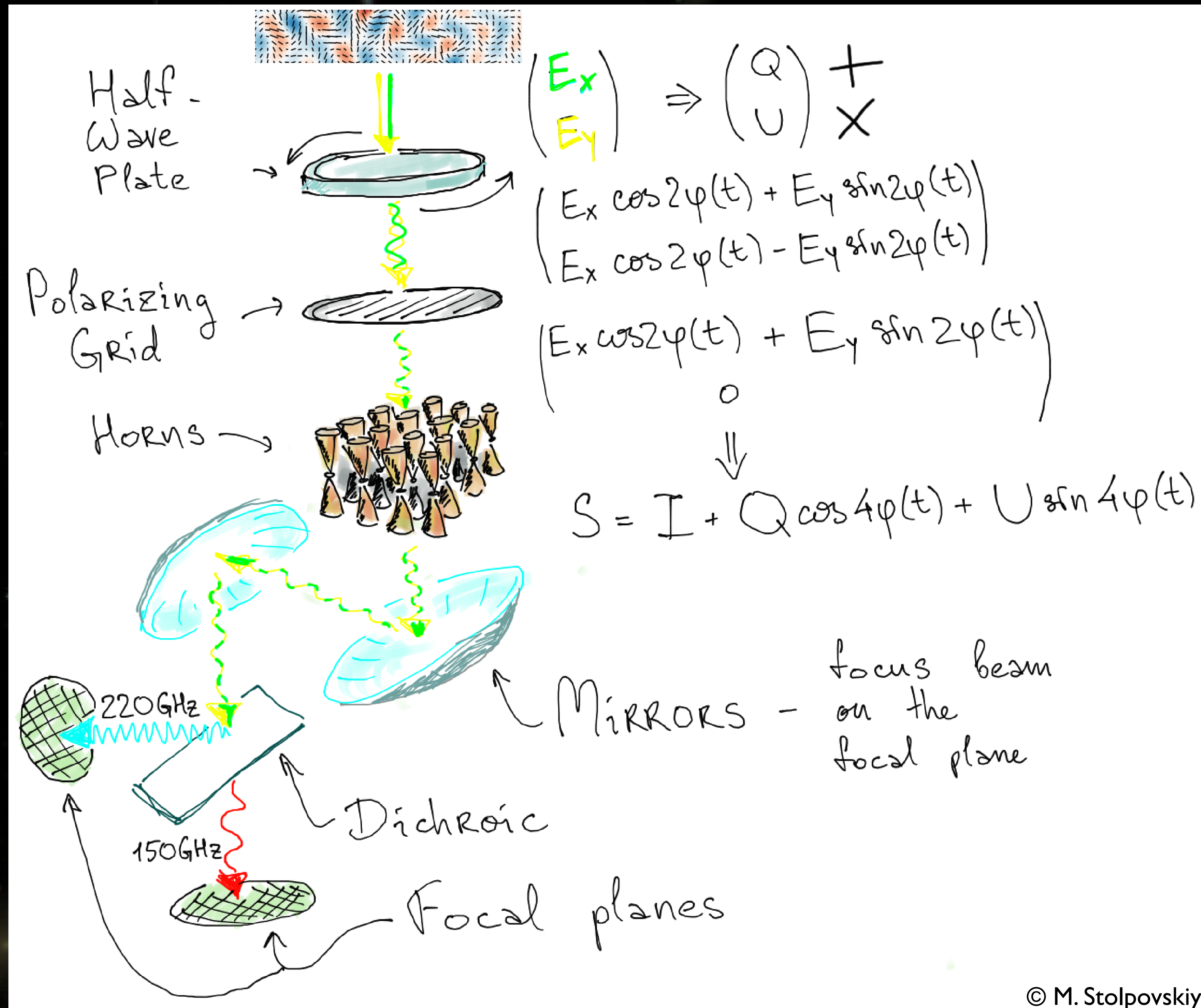
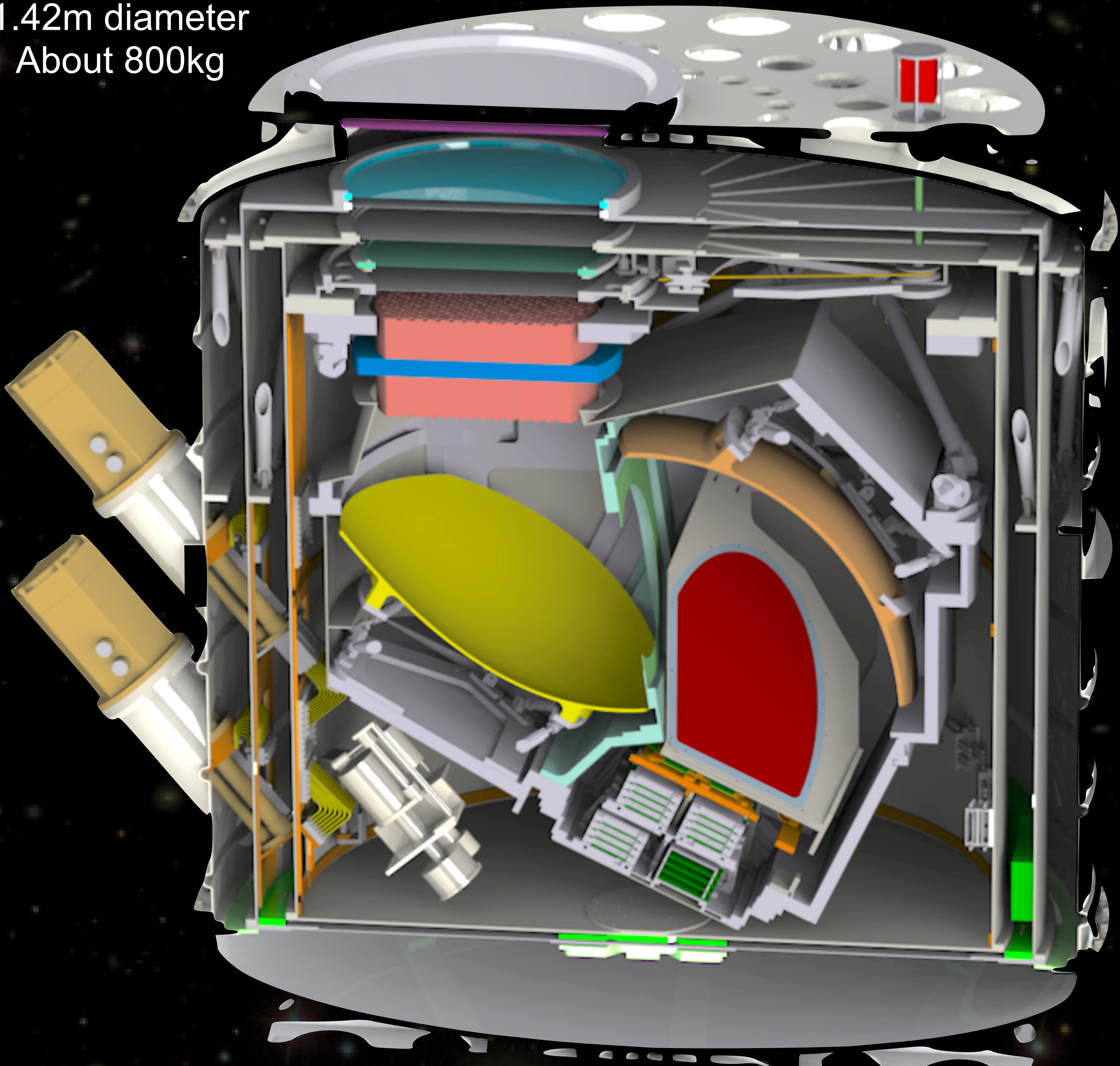






1.547m high
1.42m diameter
About 800kg

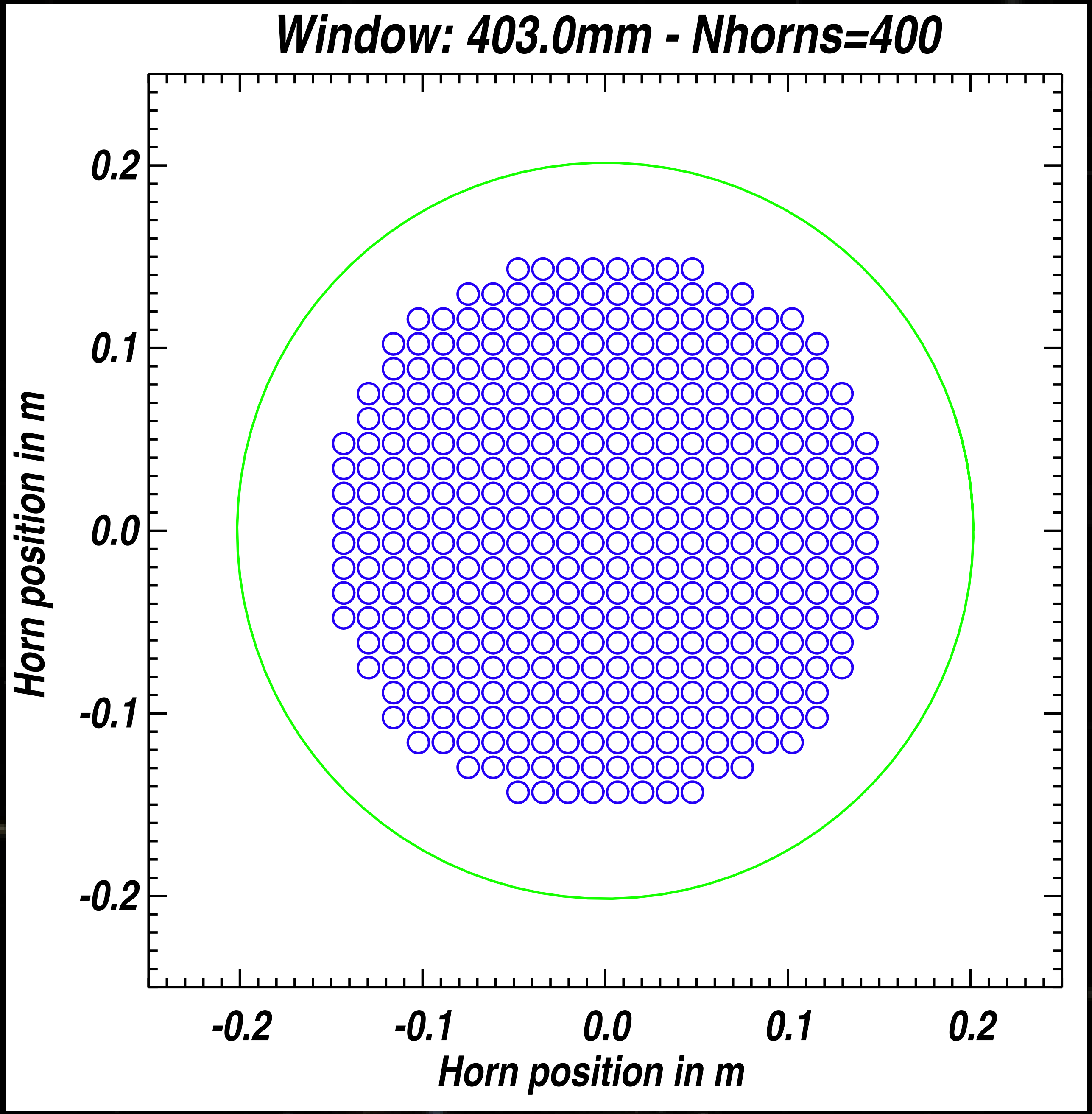
Integrated over 2018 in Paris
Now being calibrated

- Outer cryostat: **Roma**
- 1K Box / detectors: **APC, CSNSM / IRAP**
- Fridges: **Manchester**
- Optics: **Roma / Maynooth / Cardiff**
- Mount: **La Plata**
- Site: **CNEA**

Tests show expected behaviour of the instrument

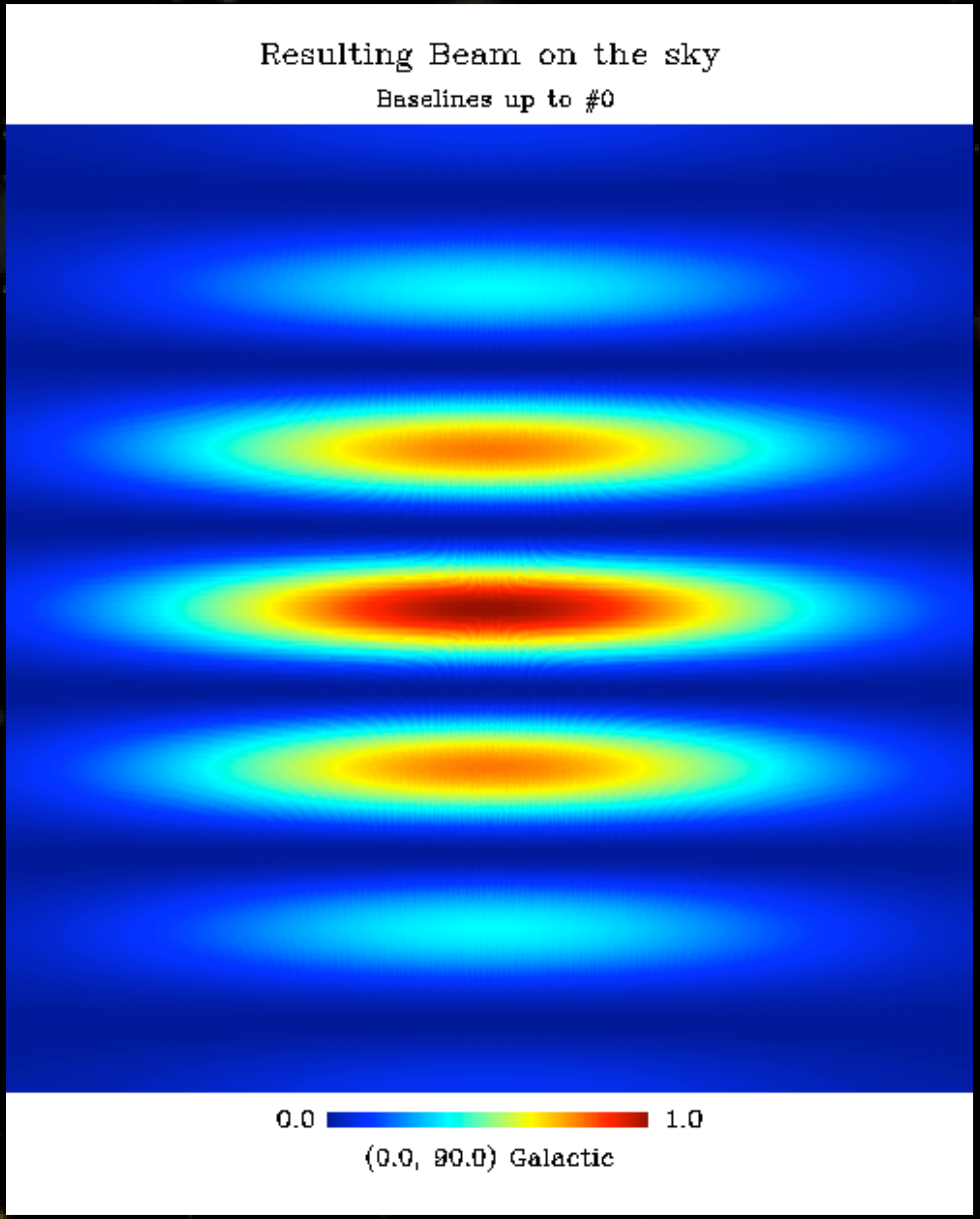
B.I. = Synthesized imager

Primary horns array



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

Synthesized beam (on the sky)



Synthesized beam used to scan the sky as with an imager

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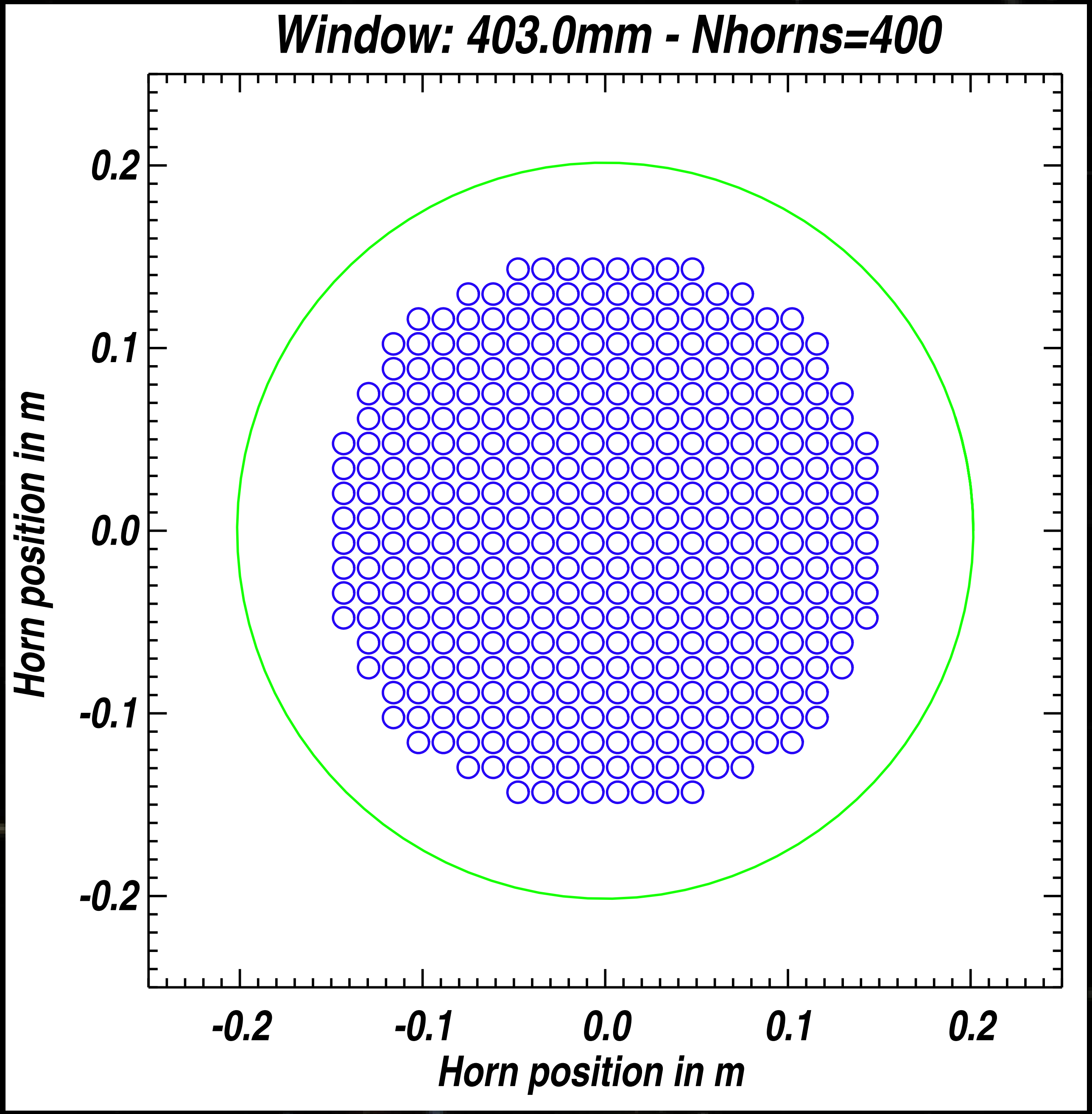

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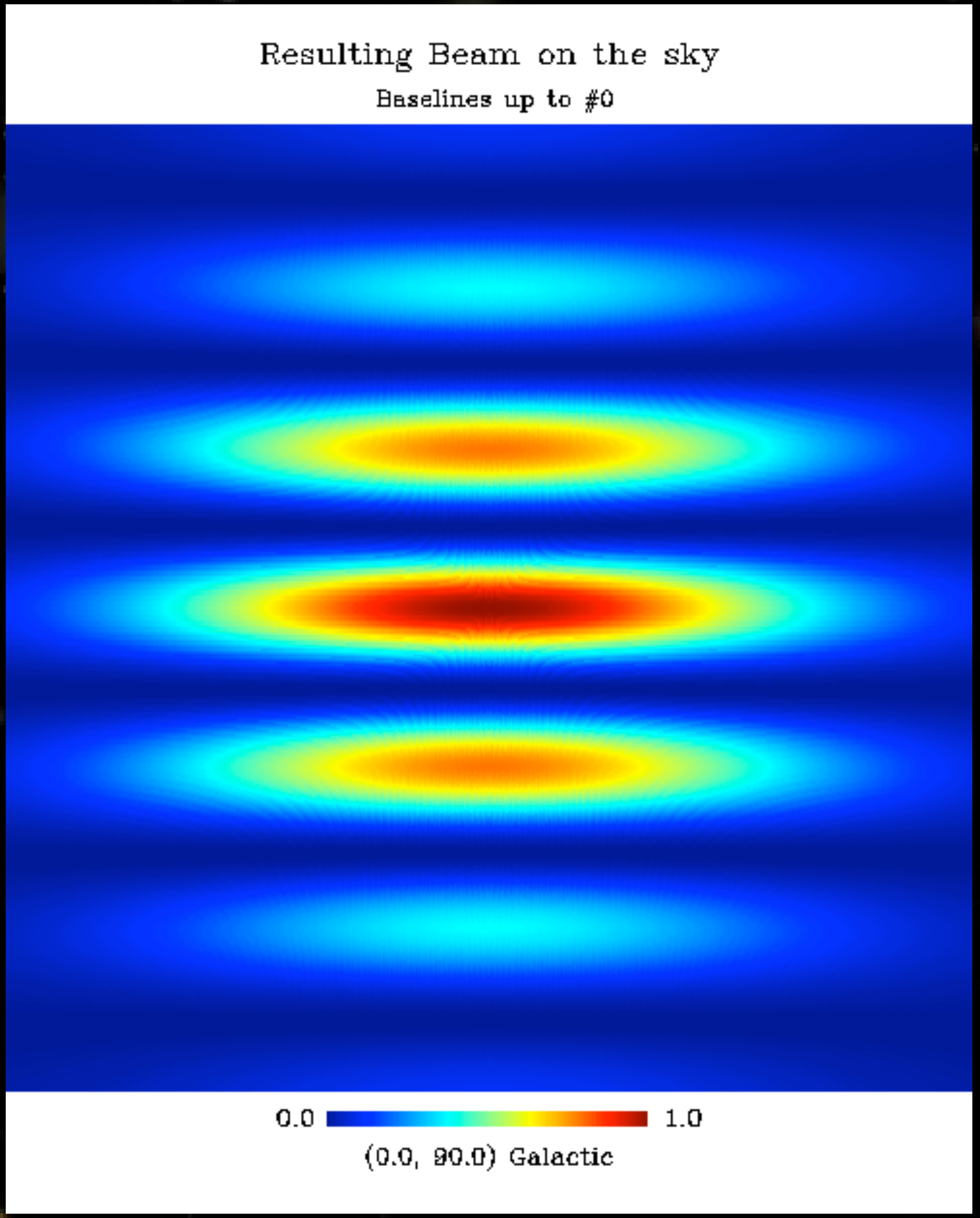

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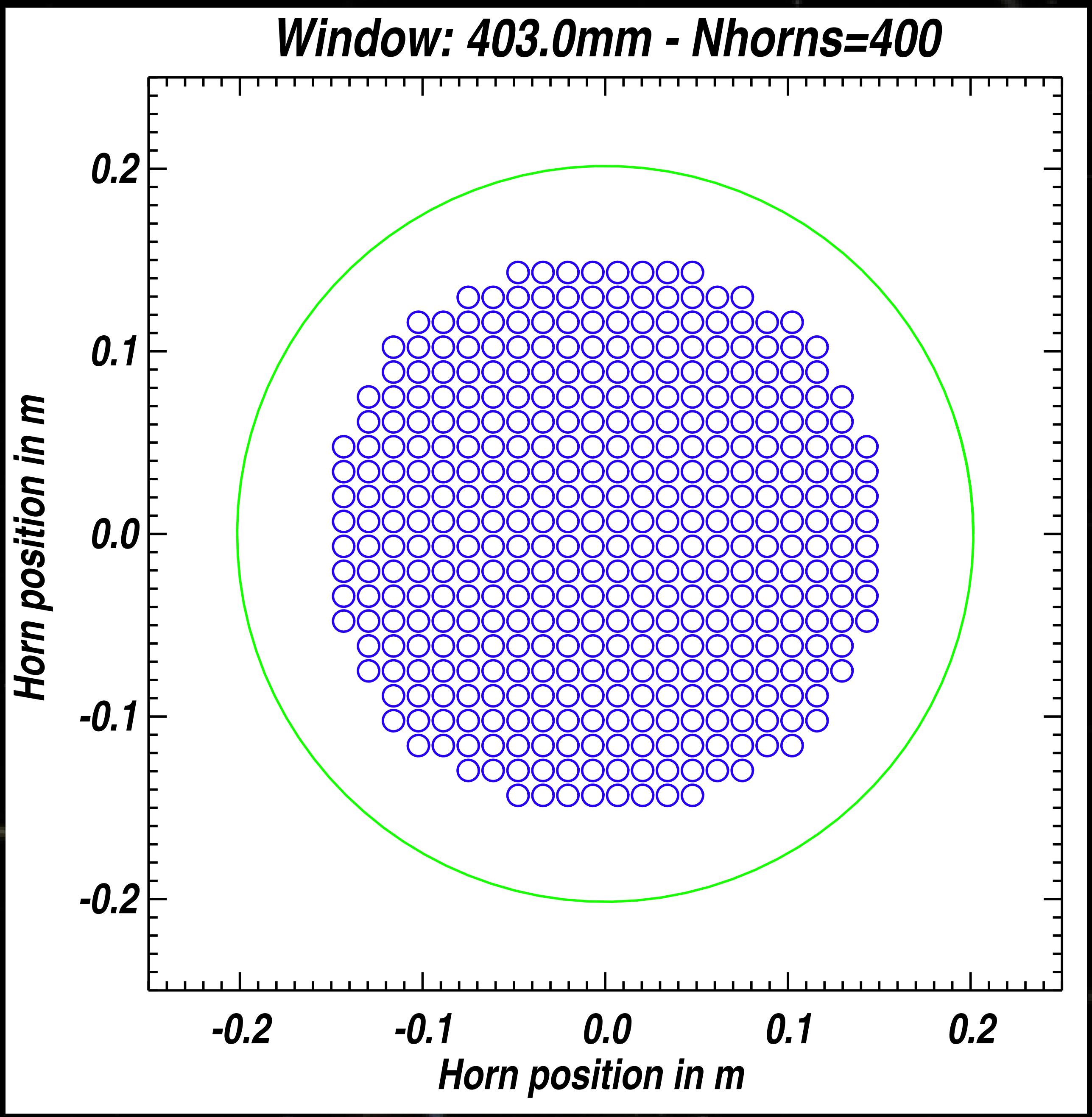

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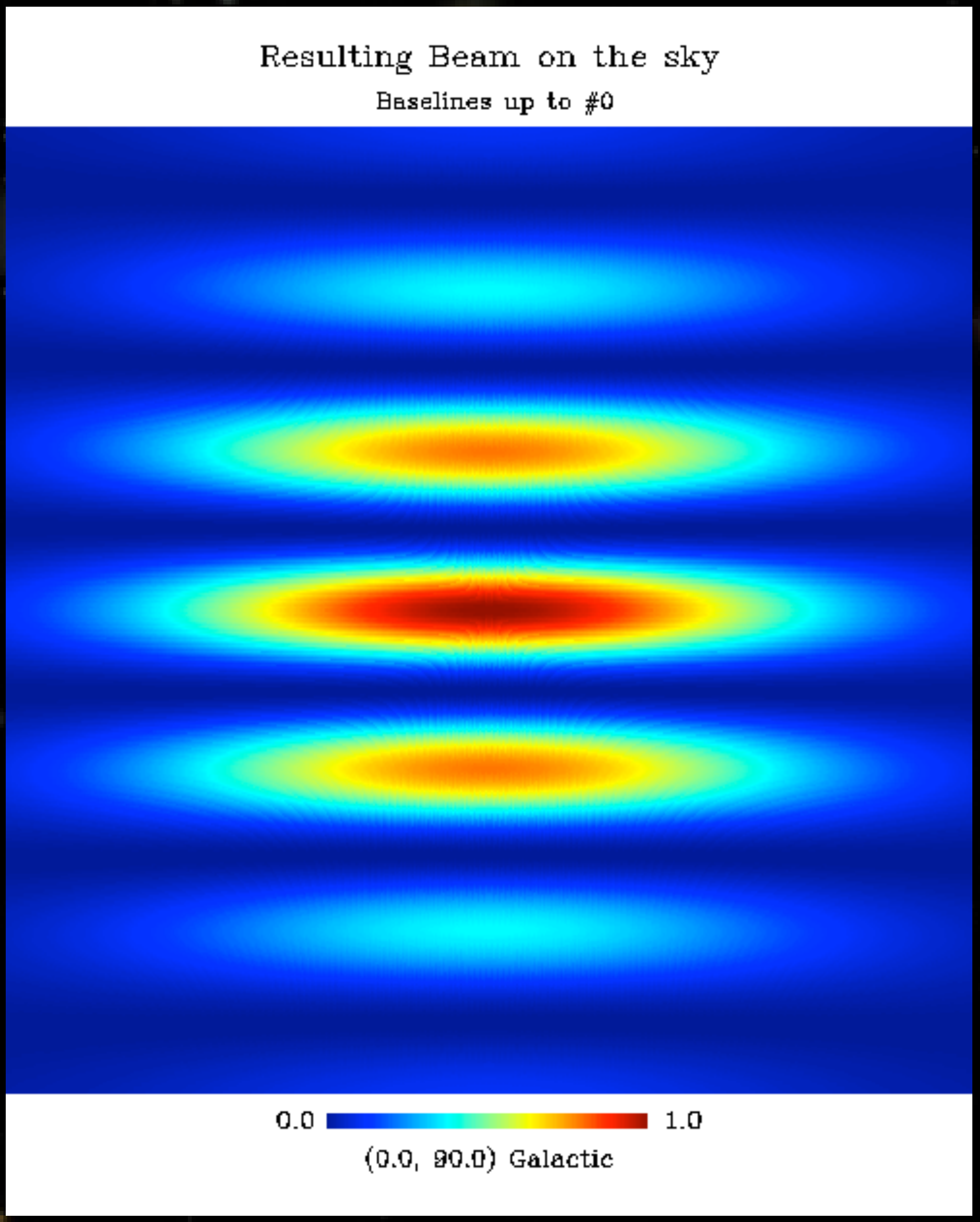

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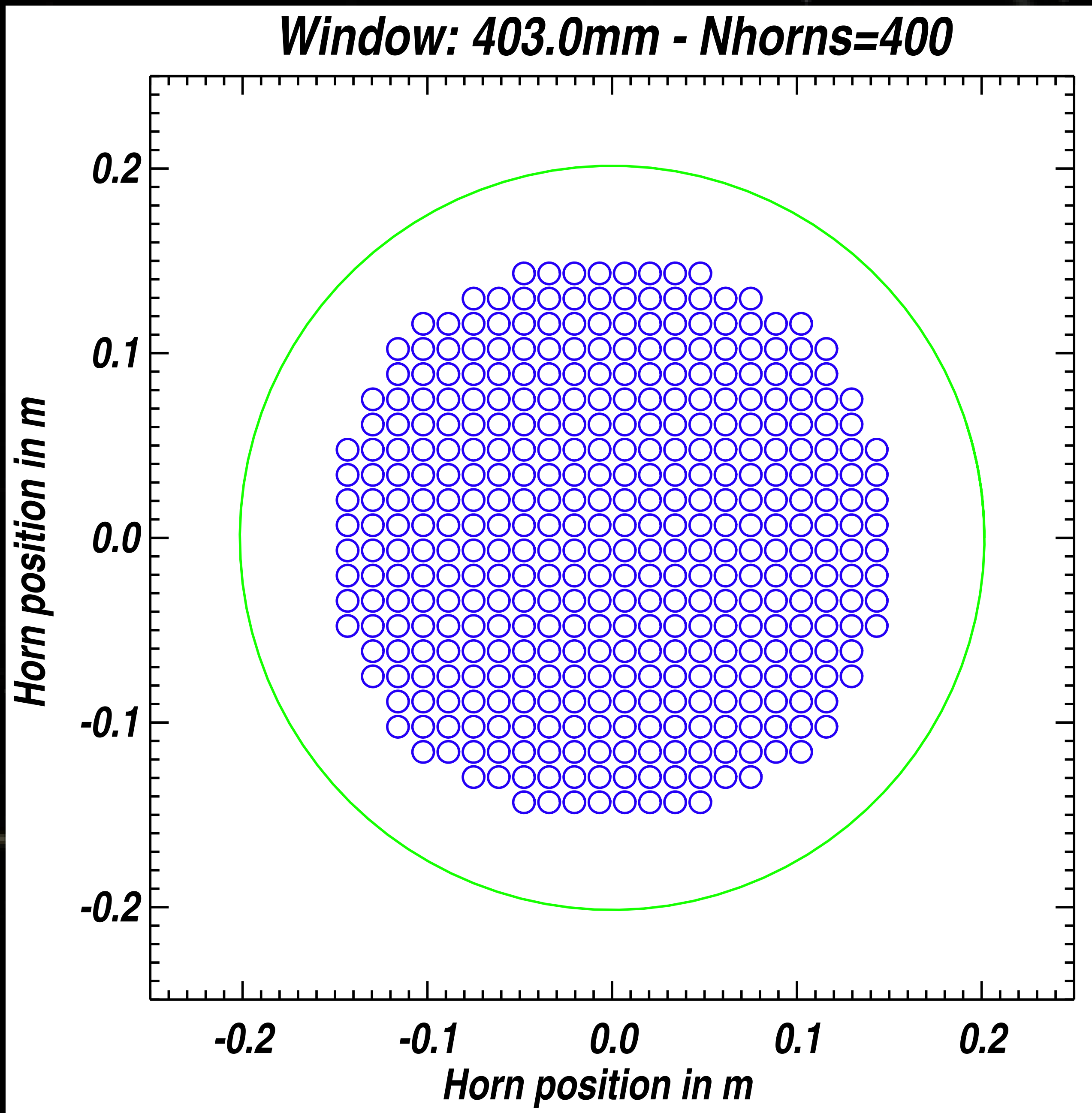

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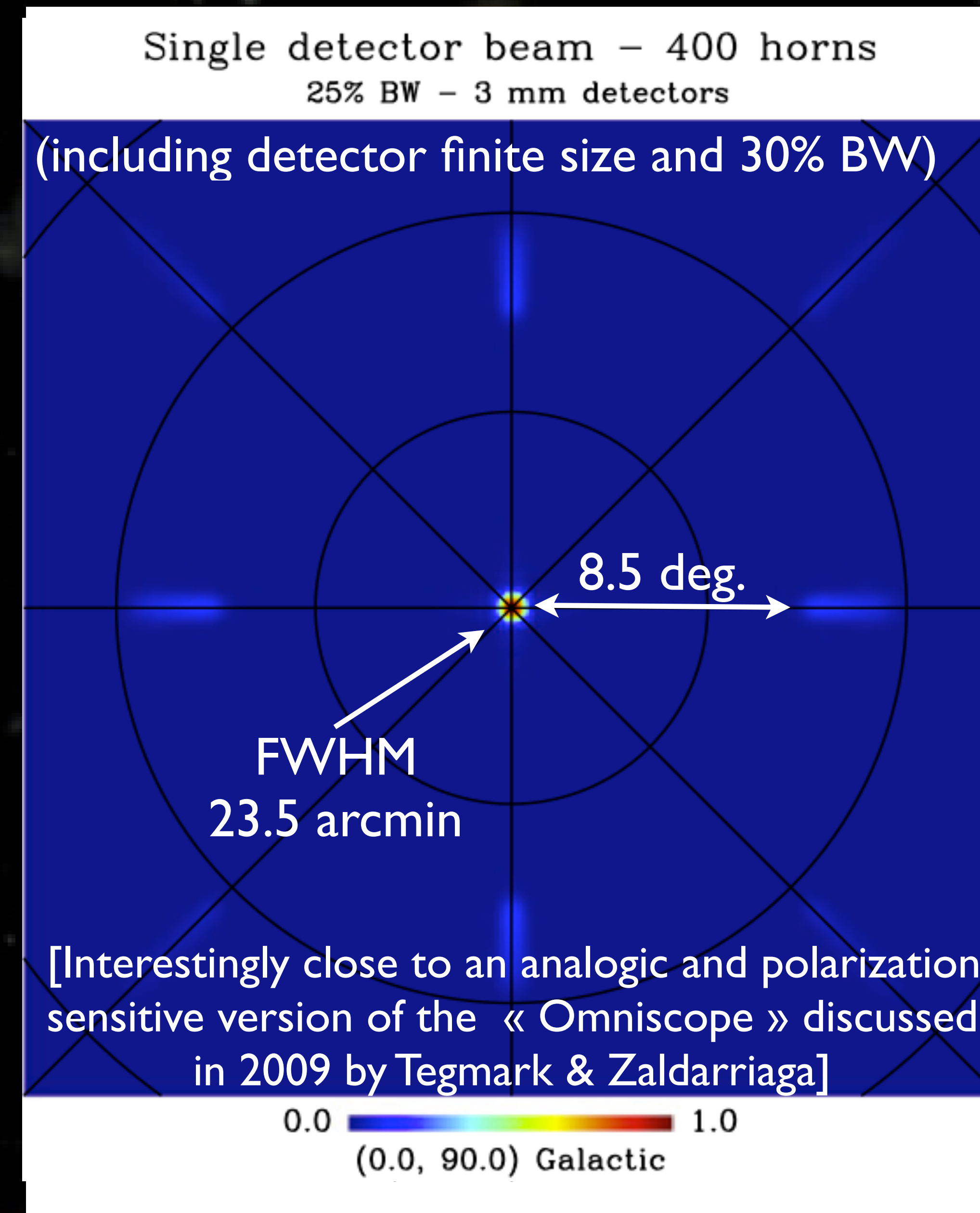
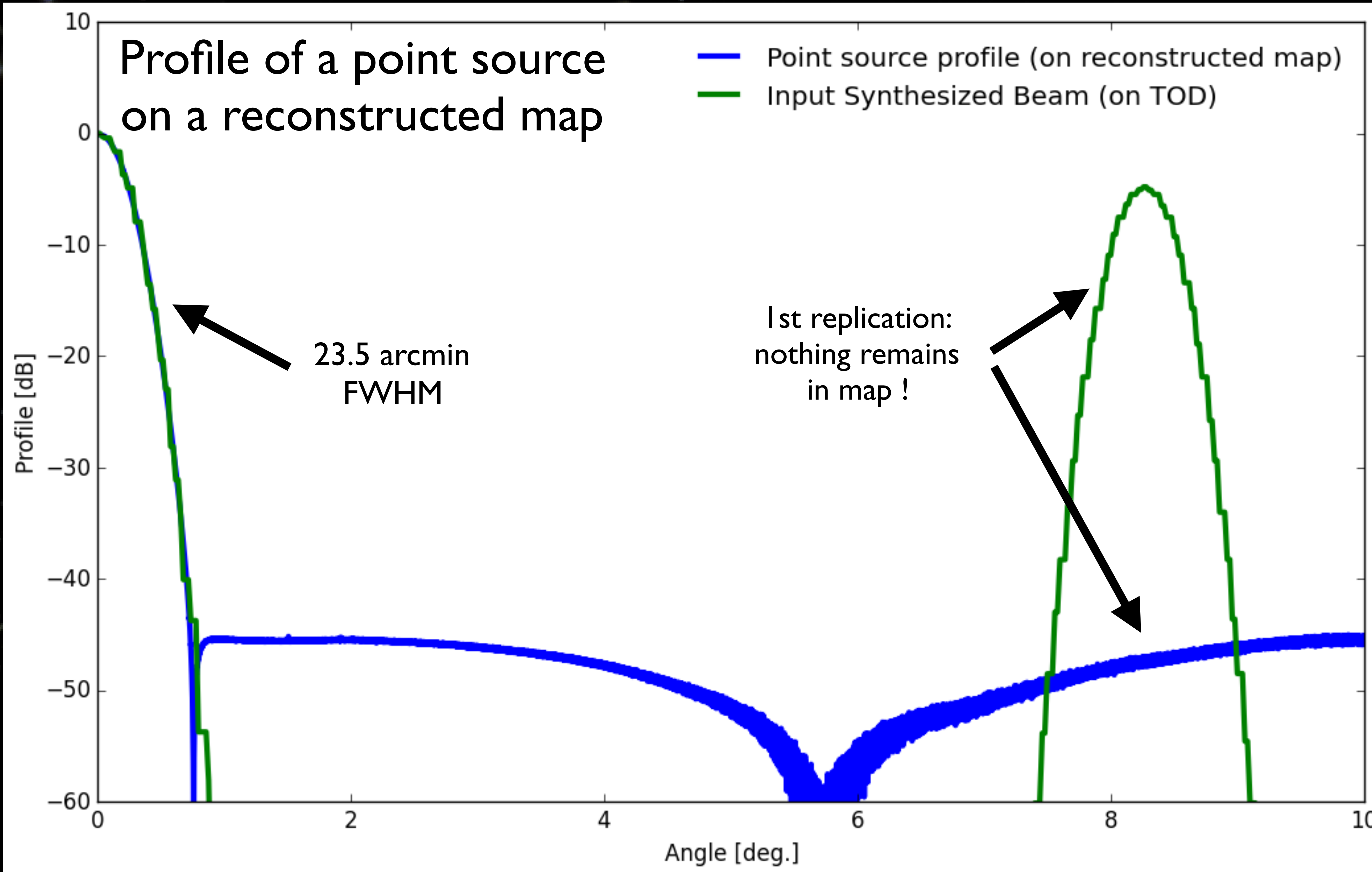
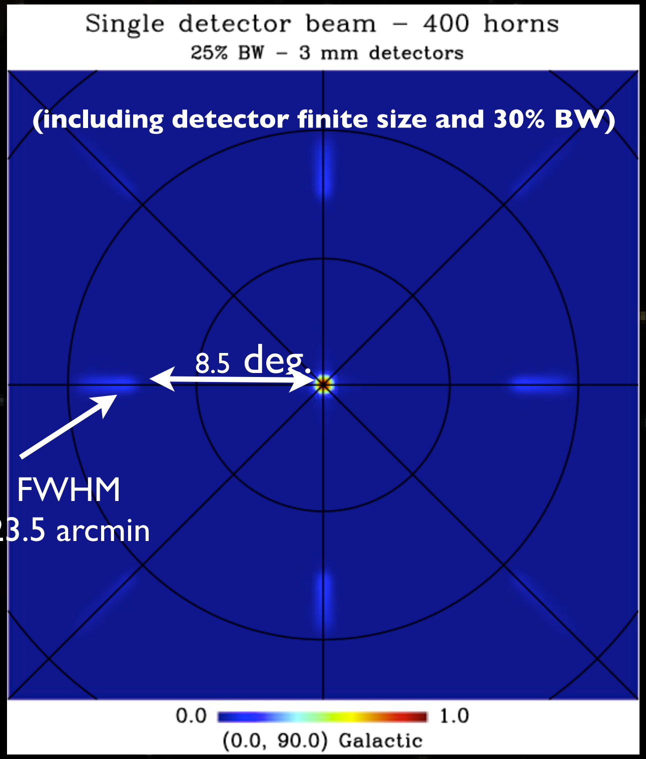


Synthesized beam used to scan
the sky as with an imager


Profile of a point source
on a reconstructed map
Point source profile (on reconstructed map)
Input Synthesized Beam (on TOD)
23.5 arcmin
FWHM
1st replication:
nothing remains
in map !
Profile [dB]
Angle [deg.]
10
0
−10
−20
−30
−40
−50
−60
0
2
4
6
8
10

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



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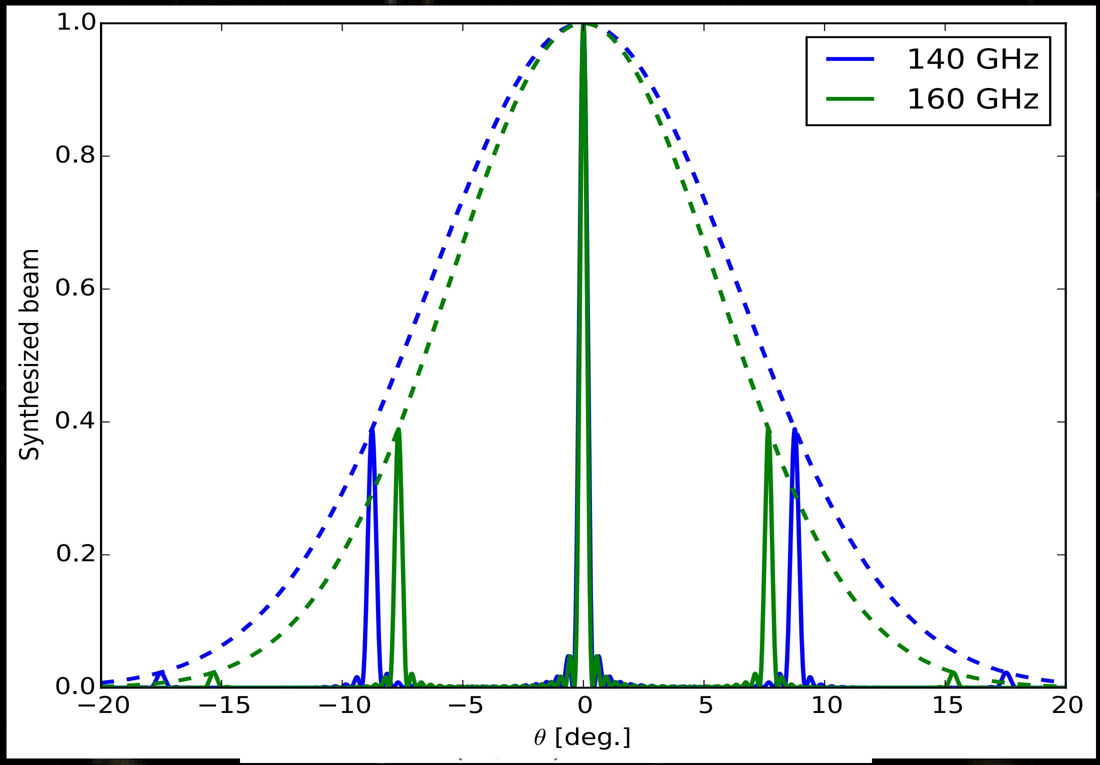

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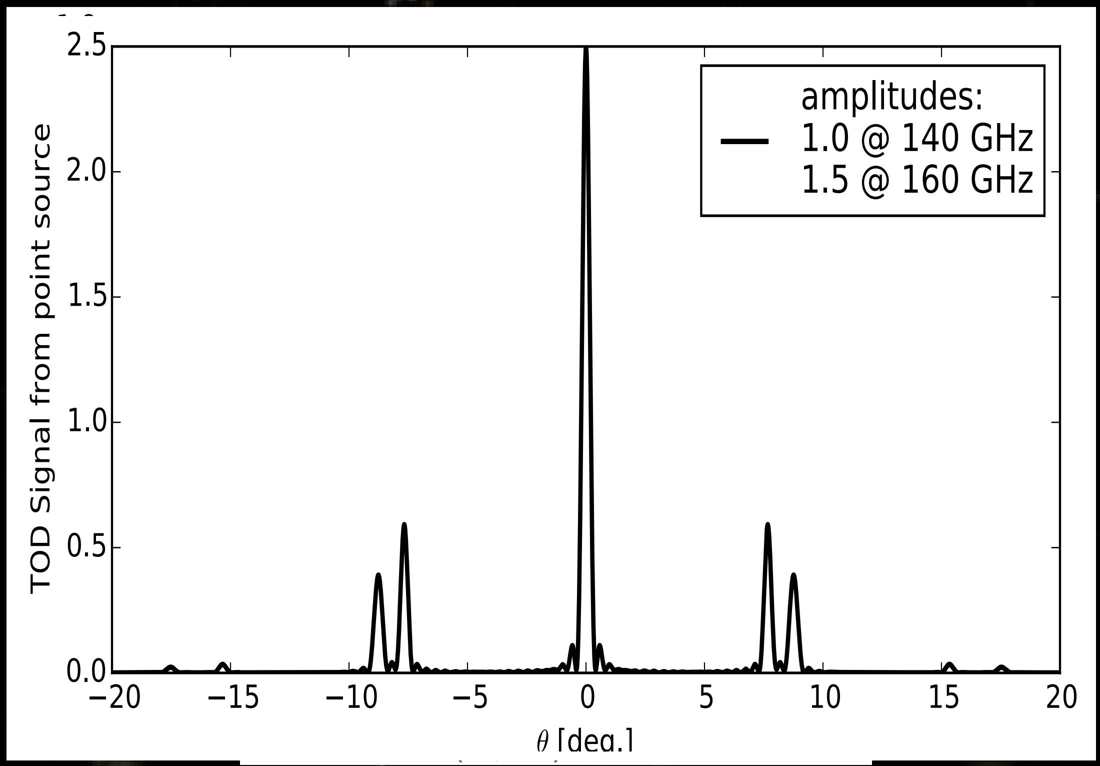

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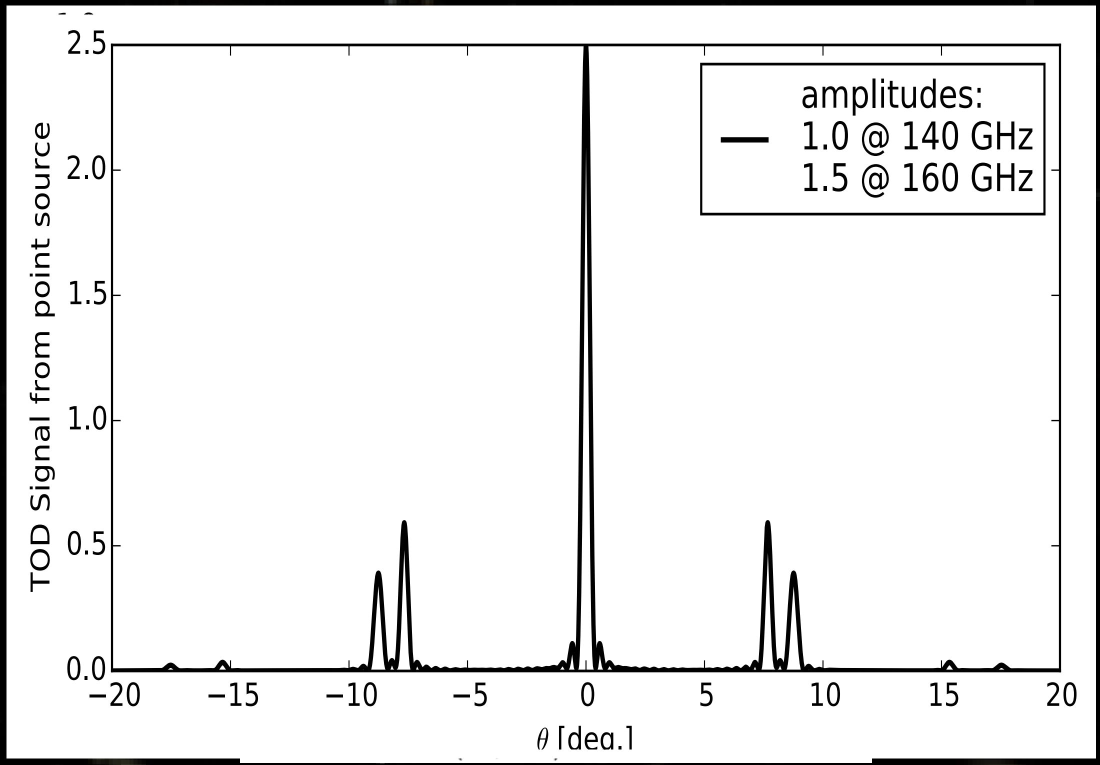

- There is spatial + frequency information !

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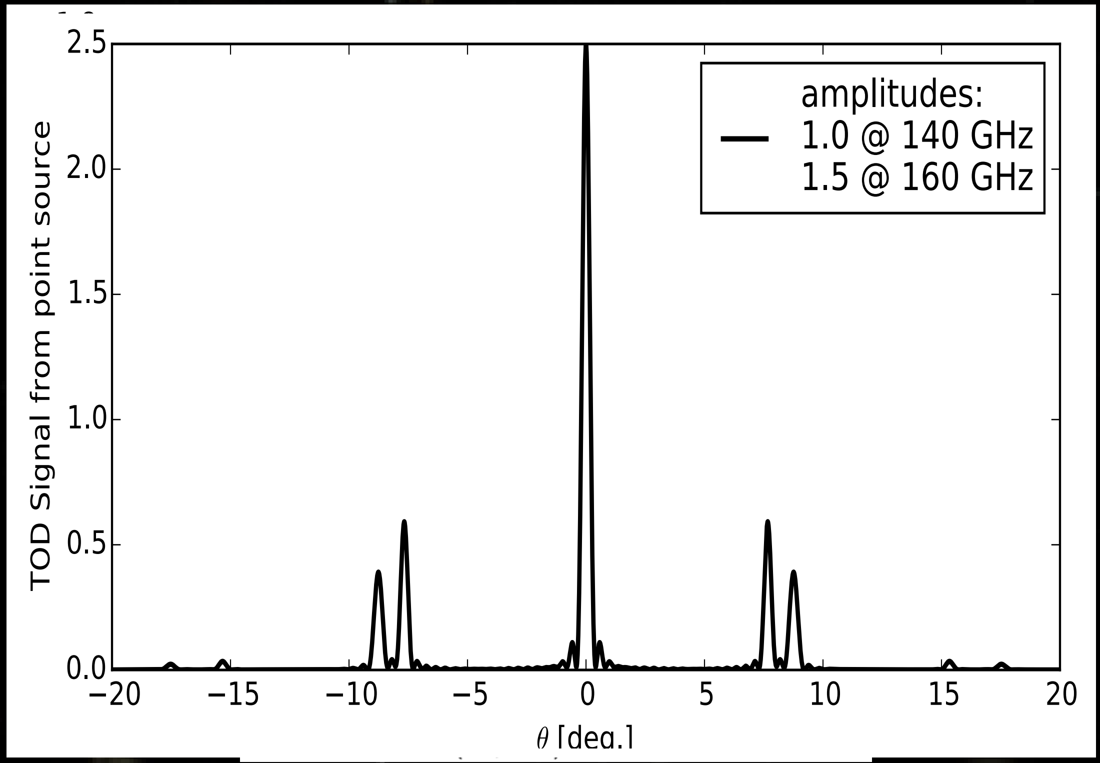
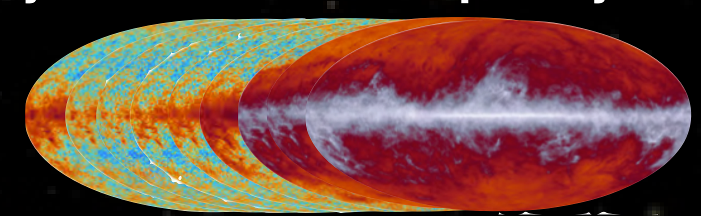


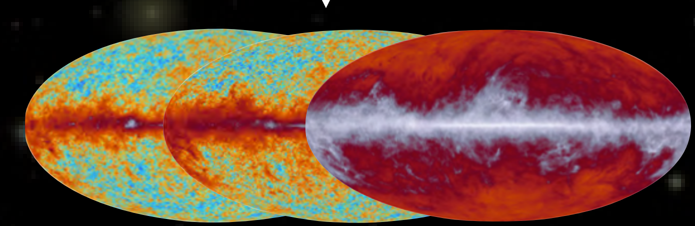
- There is spatial + frequency information !

Sky: Continuous frequency maps



$$TOD = \sum tod(\nu_i)$$

Map Making



Output: N broadband frequency maps

- 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

Data Analysis more complex but richer than with a classical imager

Complex shape of synthesized beam

↓

Map-making more complex

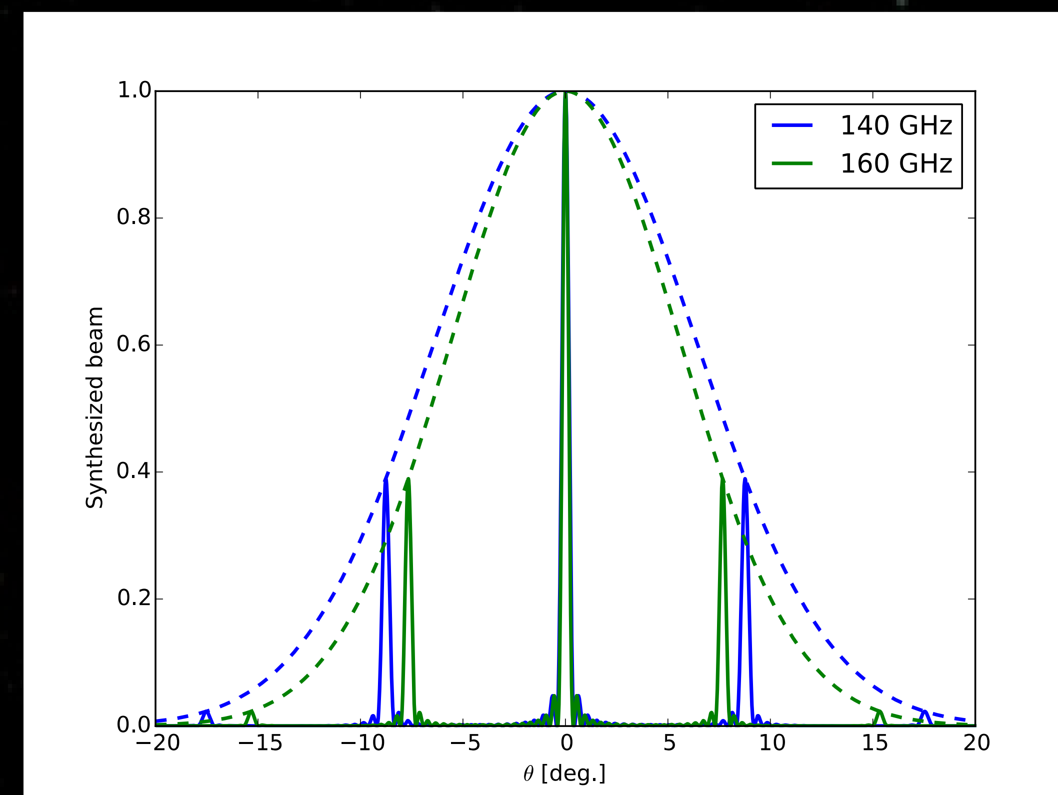
CPU…

Frequency dependence of synthesized beam

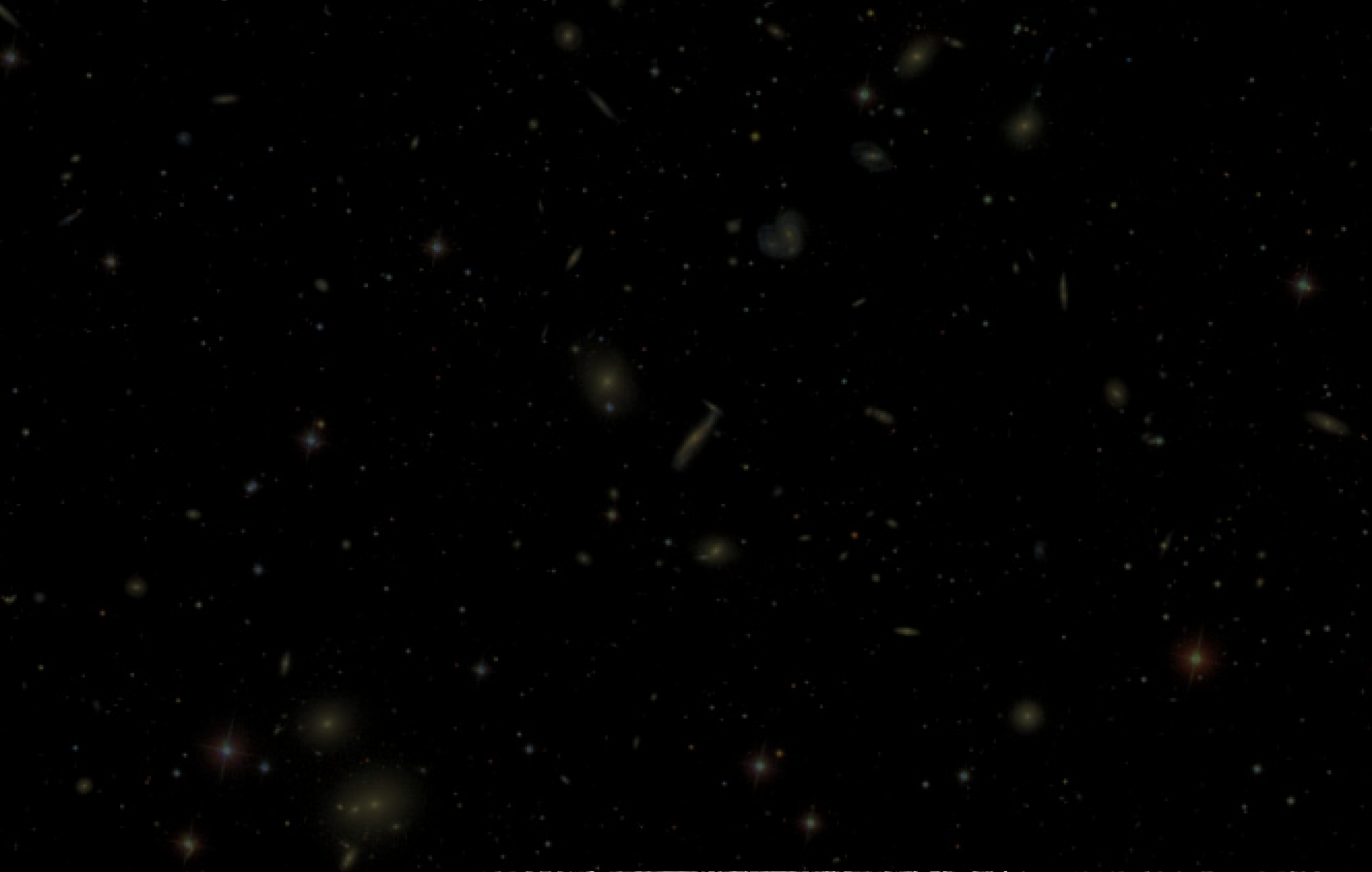
↓

Spectro-Imaging

Foregrounds!



QUBIC Spectro-Imaging



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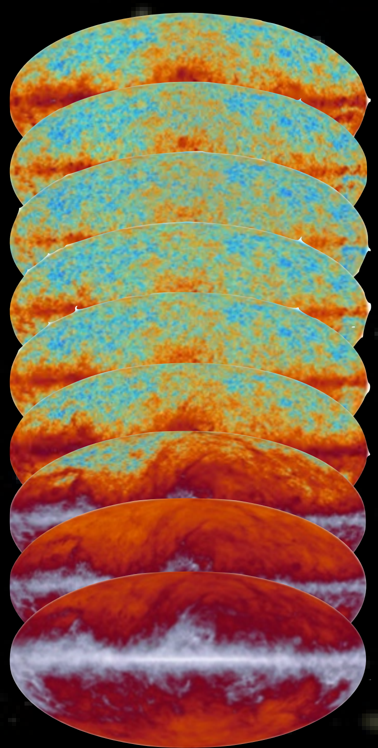
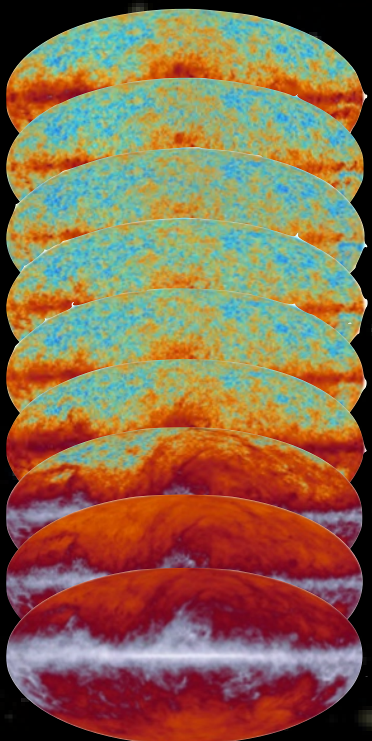
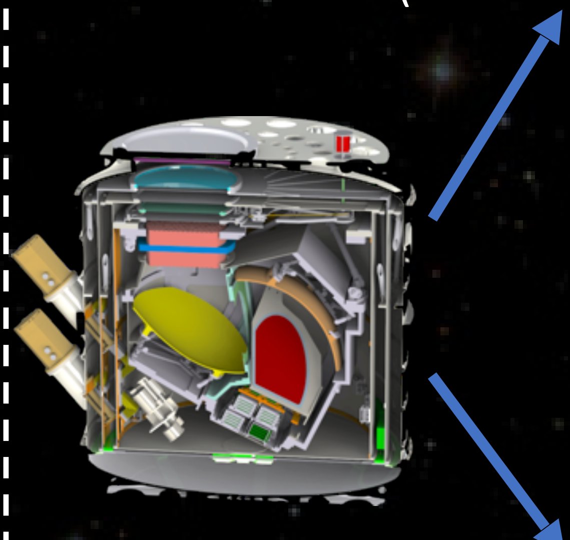


Sky:
« Infinite # bands »

QUBIC Spectro-Imaging



TOD(220 GHz)

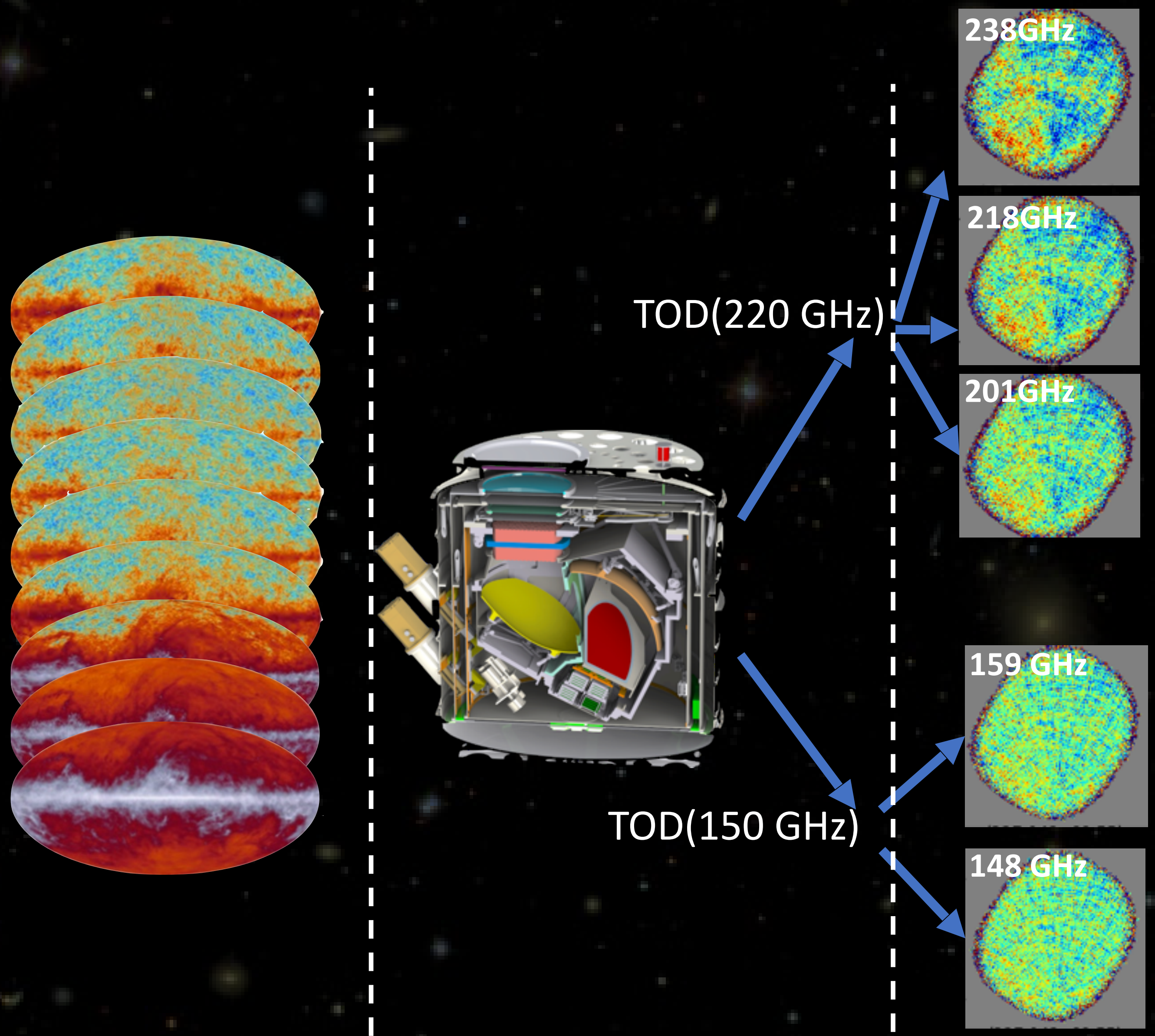


TOD(150 GHz)

Sky:
« Infinite # bands »

Instrument:
2 wide bands

QUBIC Spectro-Imaging

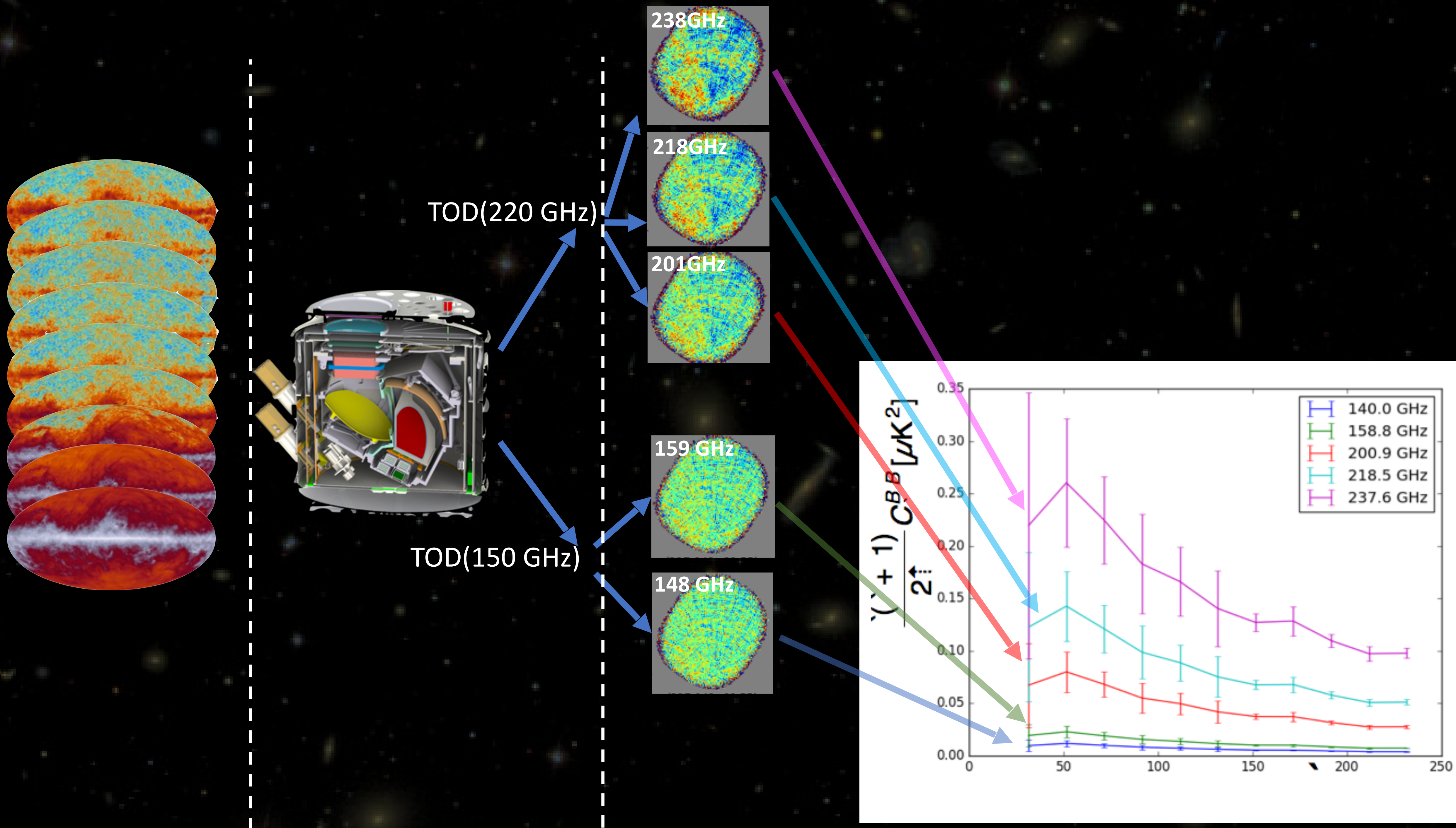


Sky:
« Infinite # bands »

Instrument:
2 wide bands

Data Analysis:
5 narrow bands

QUBIC Spectro-Imaging



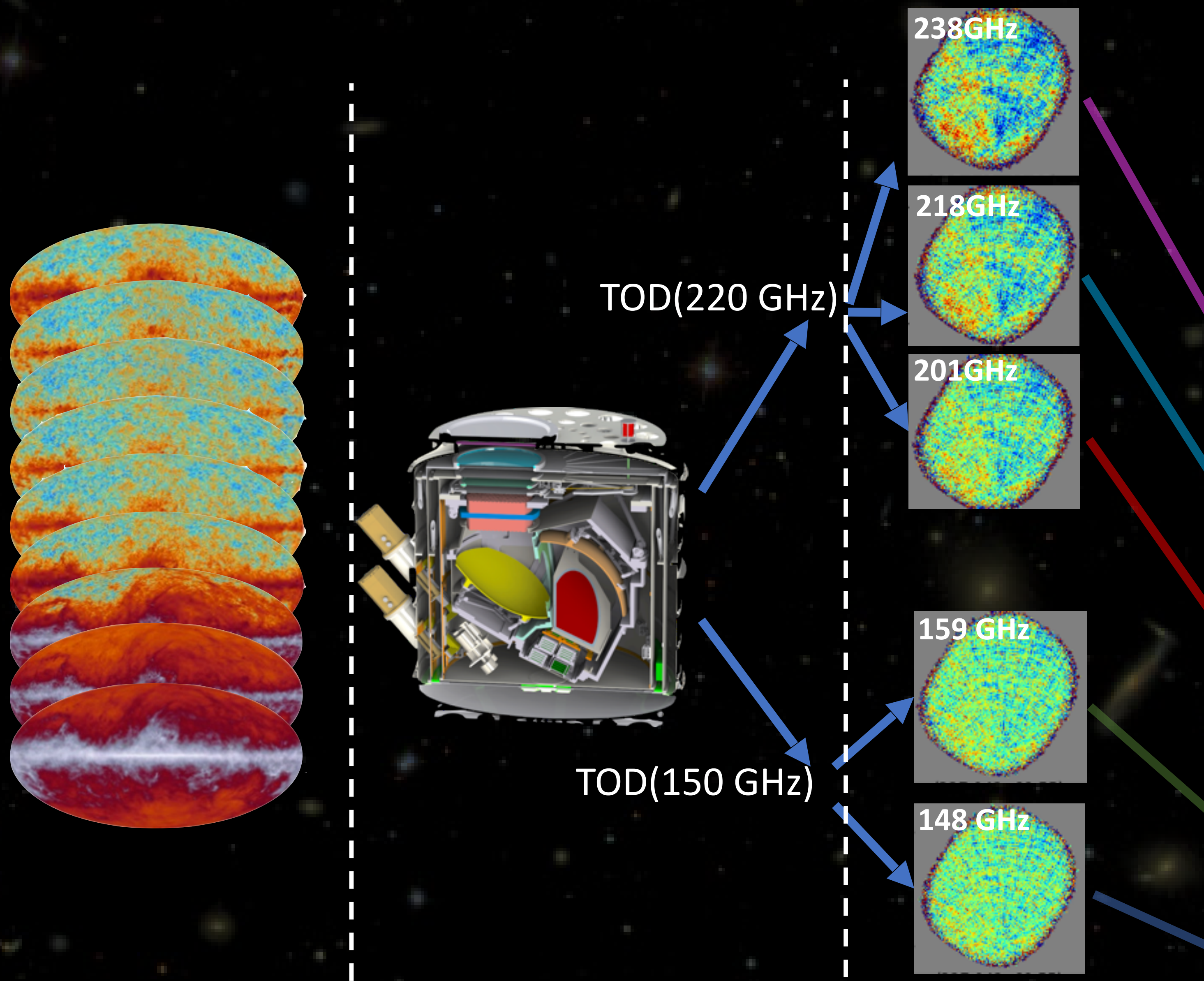
Sky:
« Infinite # bands »

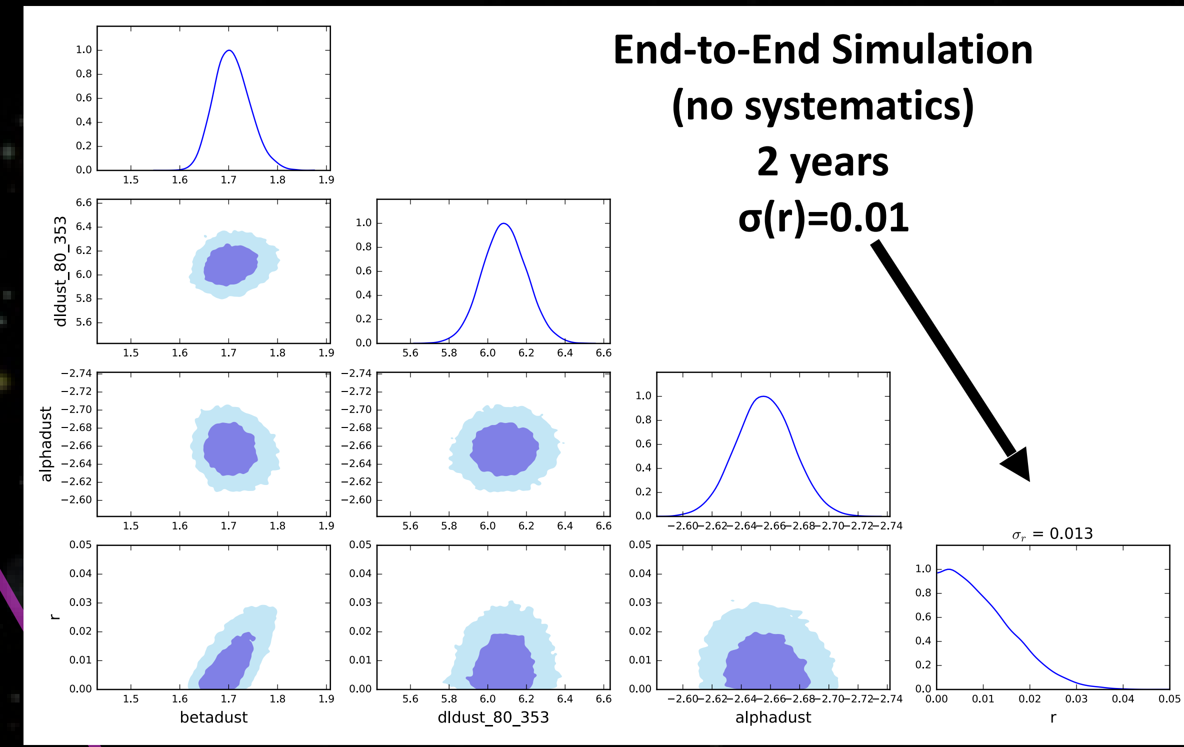
Instrument:
2 wide bands

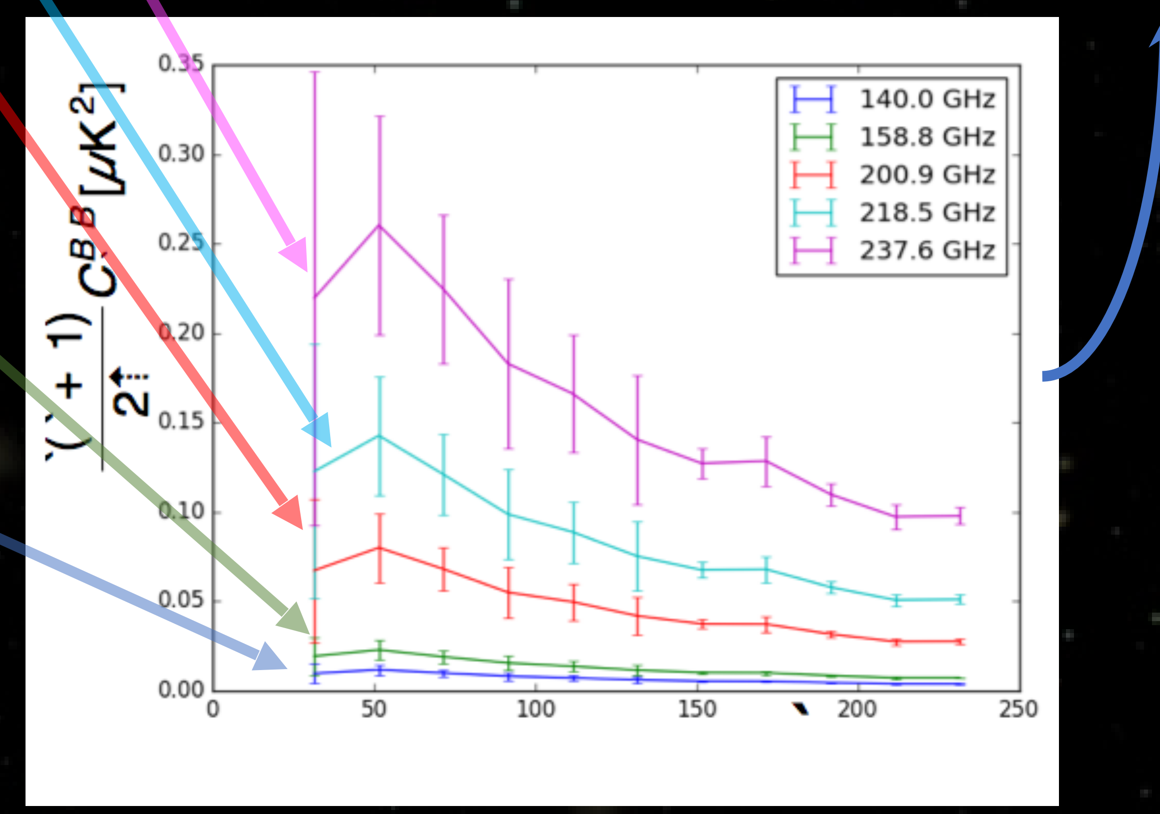
Data Analysis:
5 narrow bands

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

QUBIC Spectro-Imaging







Sky:
« Infinite # bands »

Instrument:
2 wide bands

Data Analysis:
5 narrow bands

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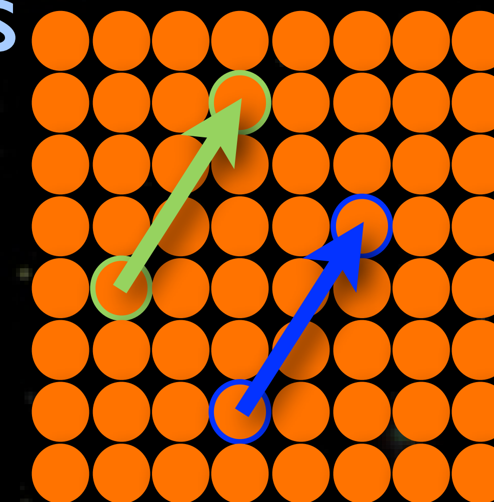
=> Dust subtraction
=> More complex models can be constrained
[specific index varying simulations being done]

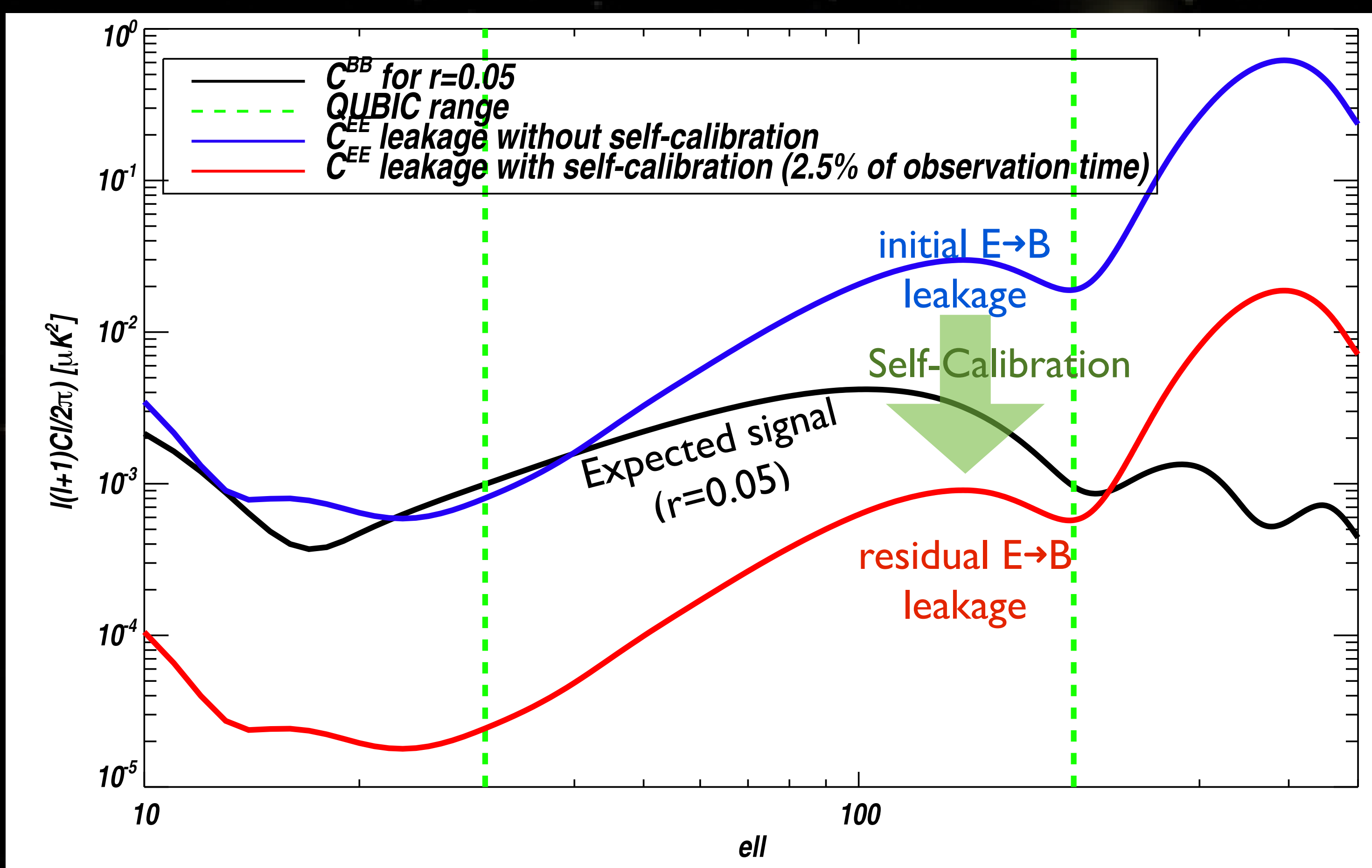
Systematics: Self-Calibration

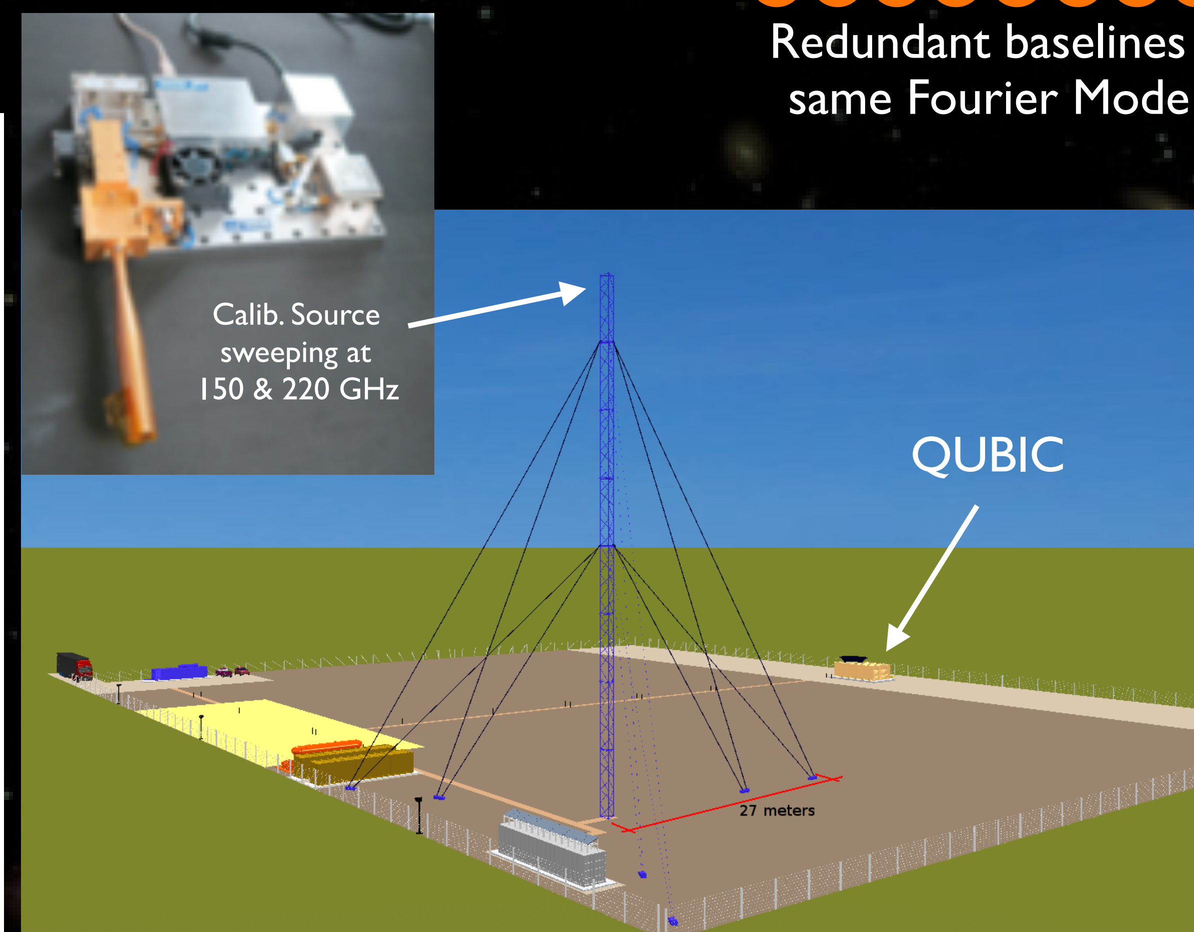
- Unique possibility to handle systematic errors
  - ★ Use horn array redundancy to calibrate systematics
    - In a perfect instrument redundant baselines should see the same signal
    - Differences due to systematics
    - Allow to fit systematics with an external source on the field
  - ★ Unique specificity of Bolometric Interferometry !

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



Redundant baselines : same Fourier Mode

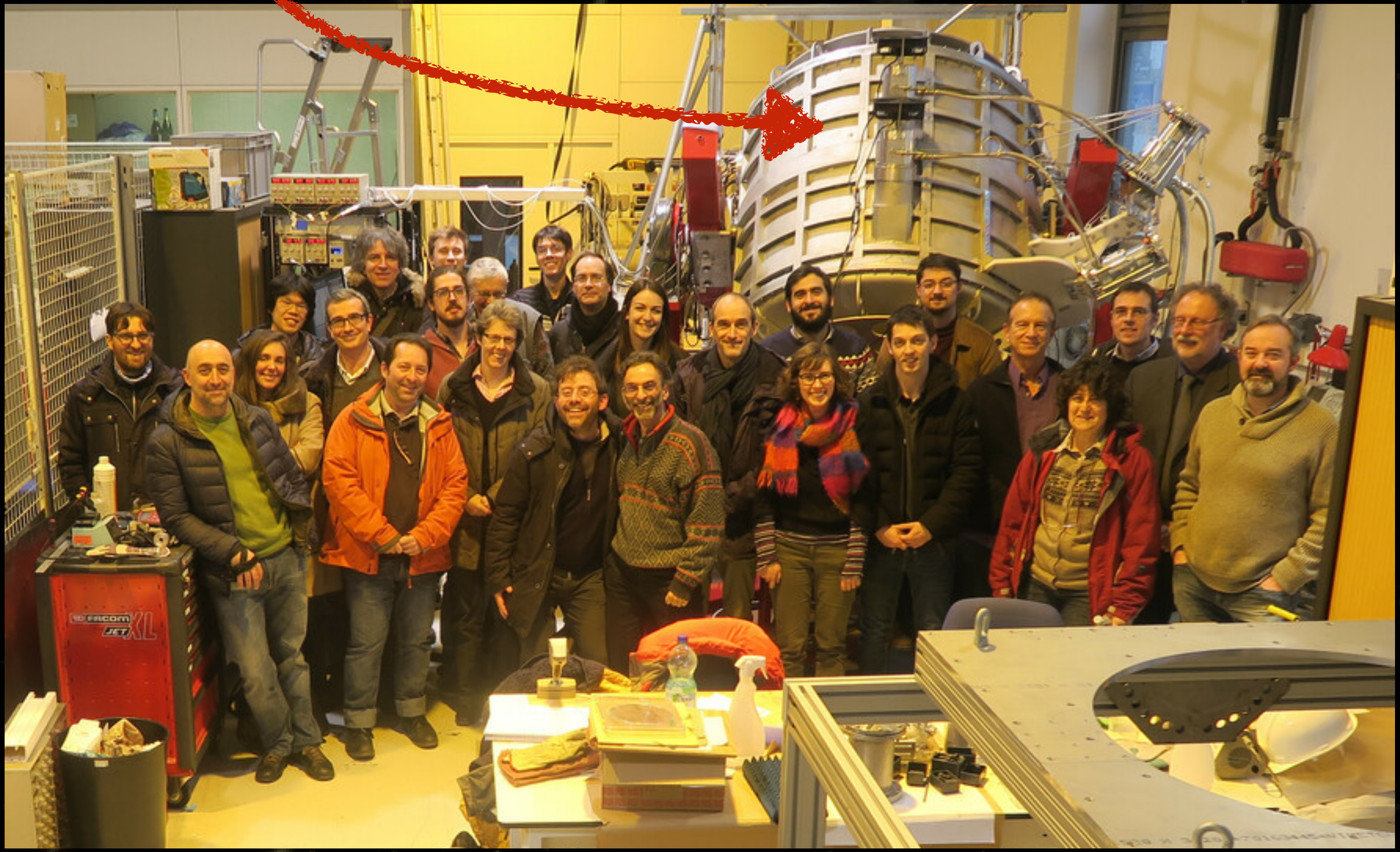




QUBIC Hardware

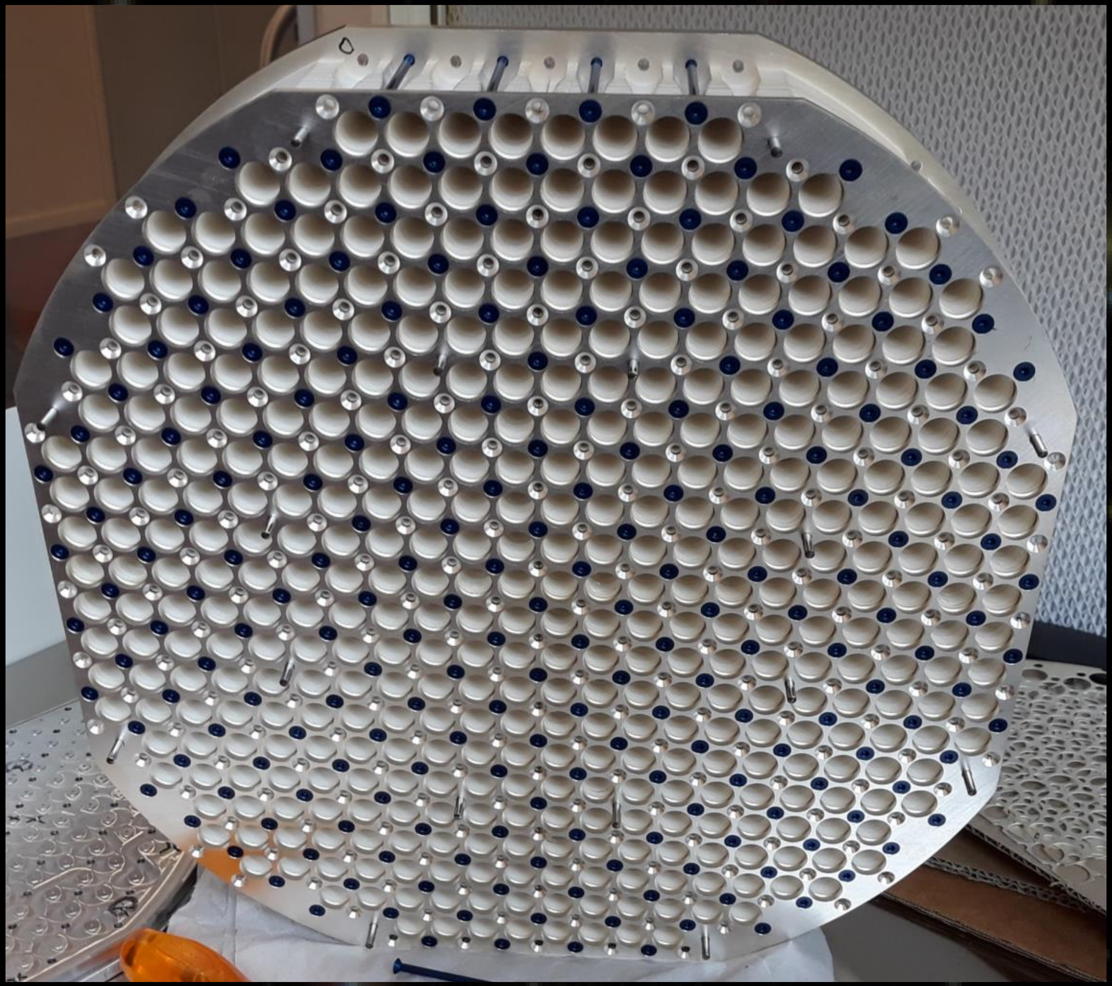
Cryostat designed and manufactured in Roma - La Sapienza

At 4K continuously since Jan. 2019
~50 cycles of the 300mK fridge

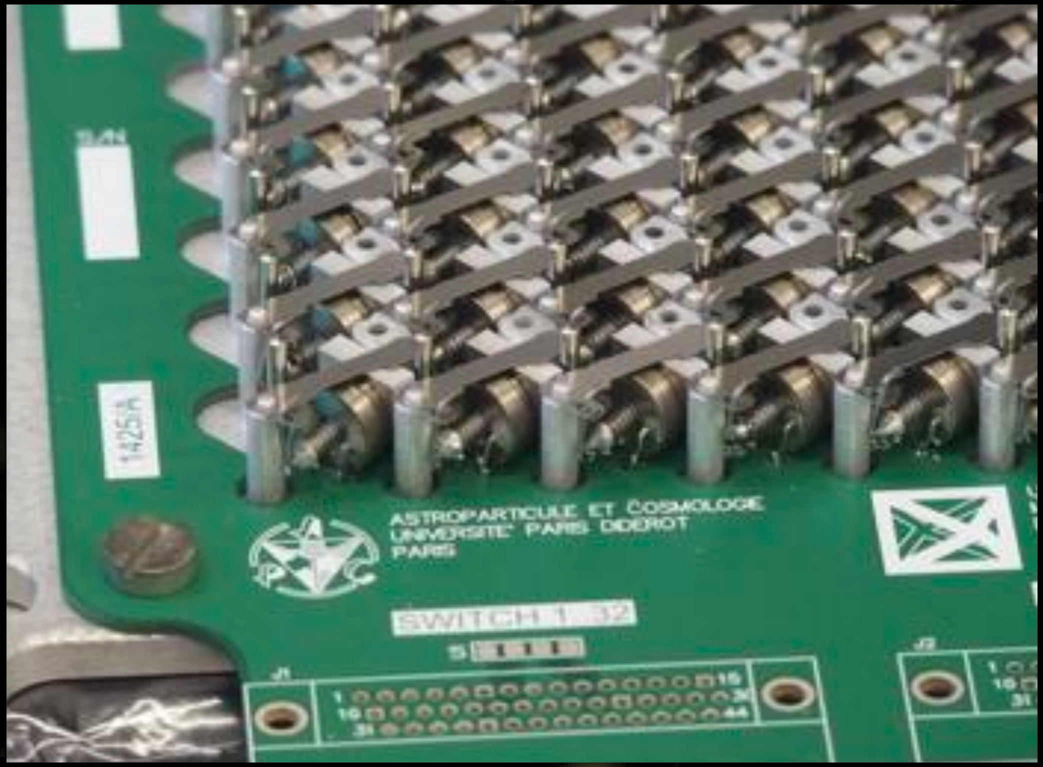


QUBIC Hardware

B2B platelets horn-array
Milano Statale



Switches and electronics
Milano Bicocca + APC



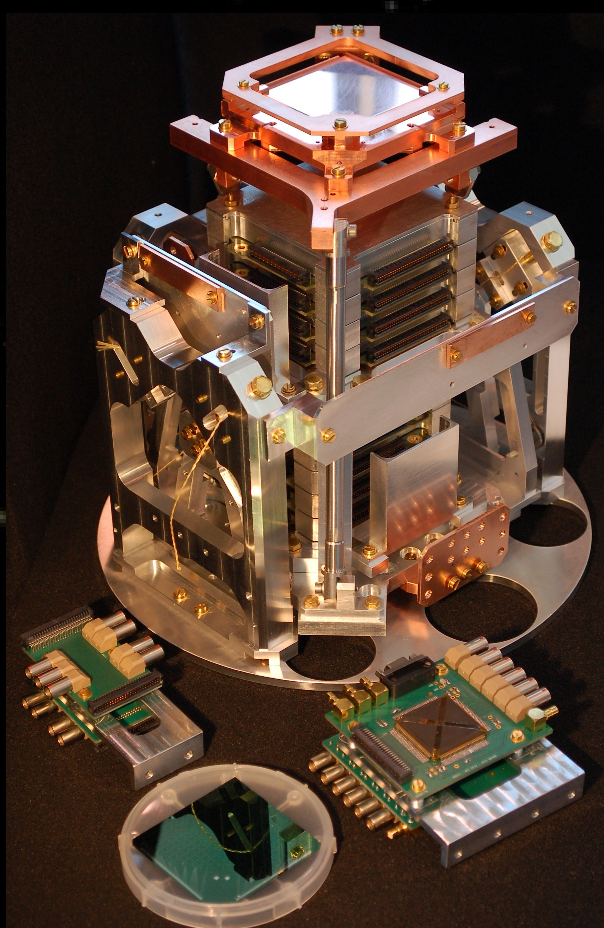
QUBIC Hardware

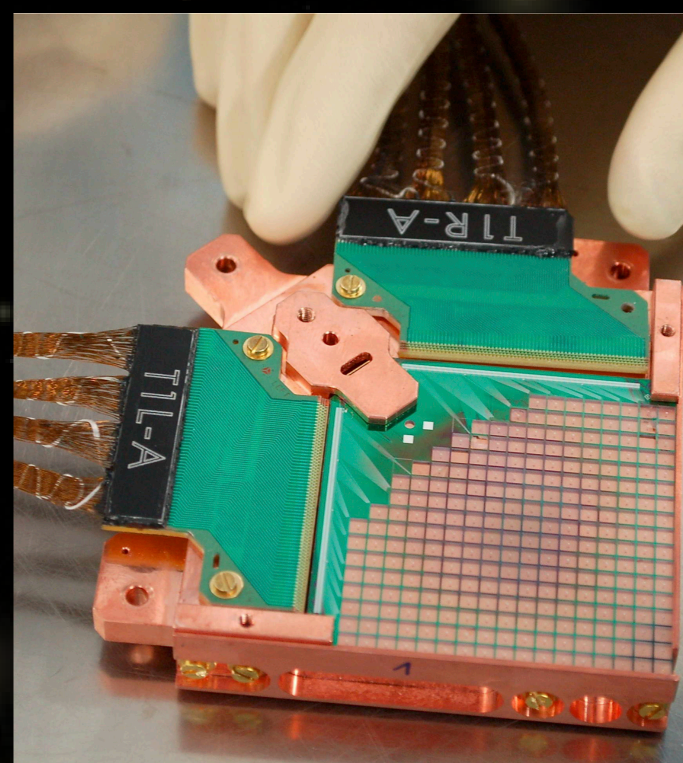
QUBIC HWP Rotator
Roma - La Sapienza

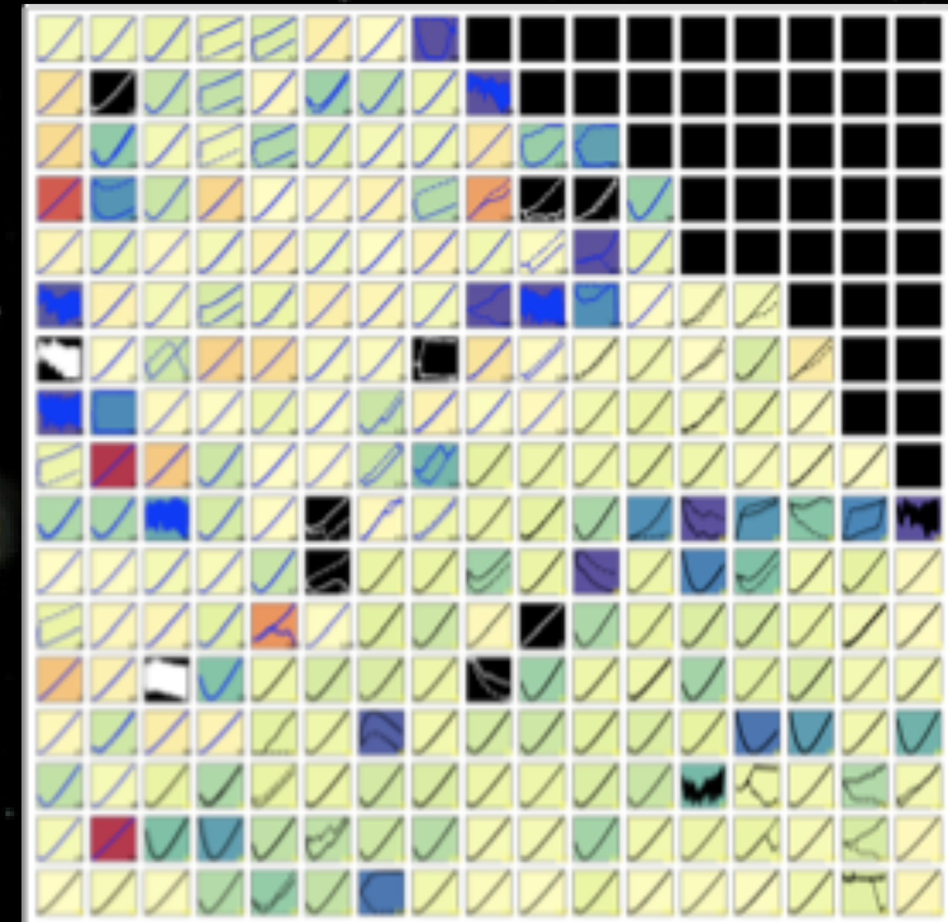
QUBIC Hardware

Detection chain
APC-CSNSM-IRAP

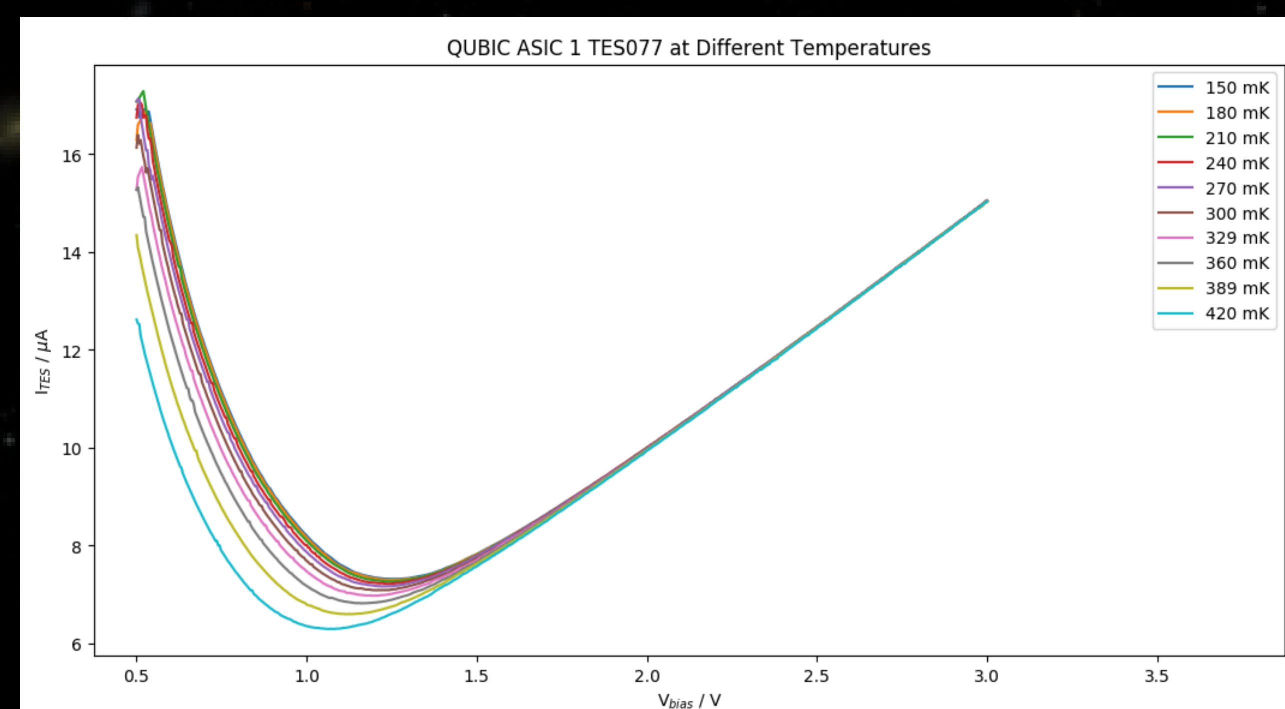
1:128 SQUIDs+ASIC Mux
2048 TES Bolometers
(256 for TD)





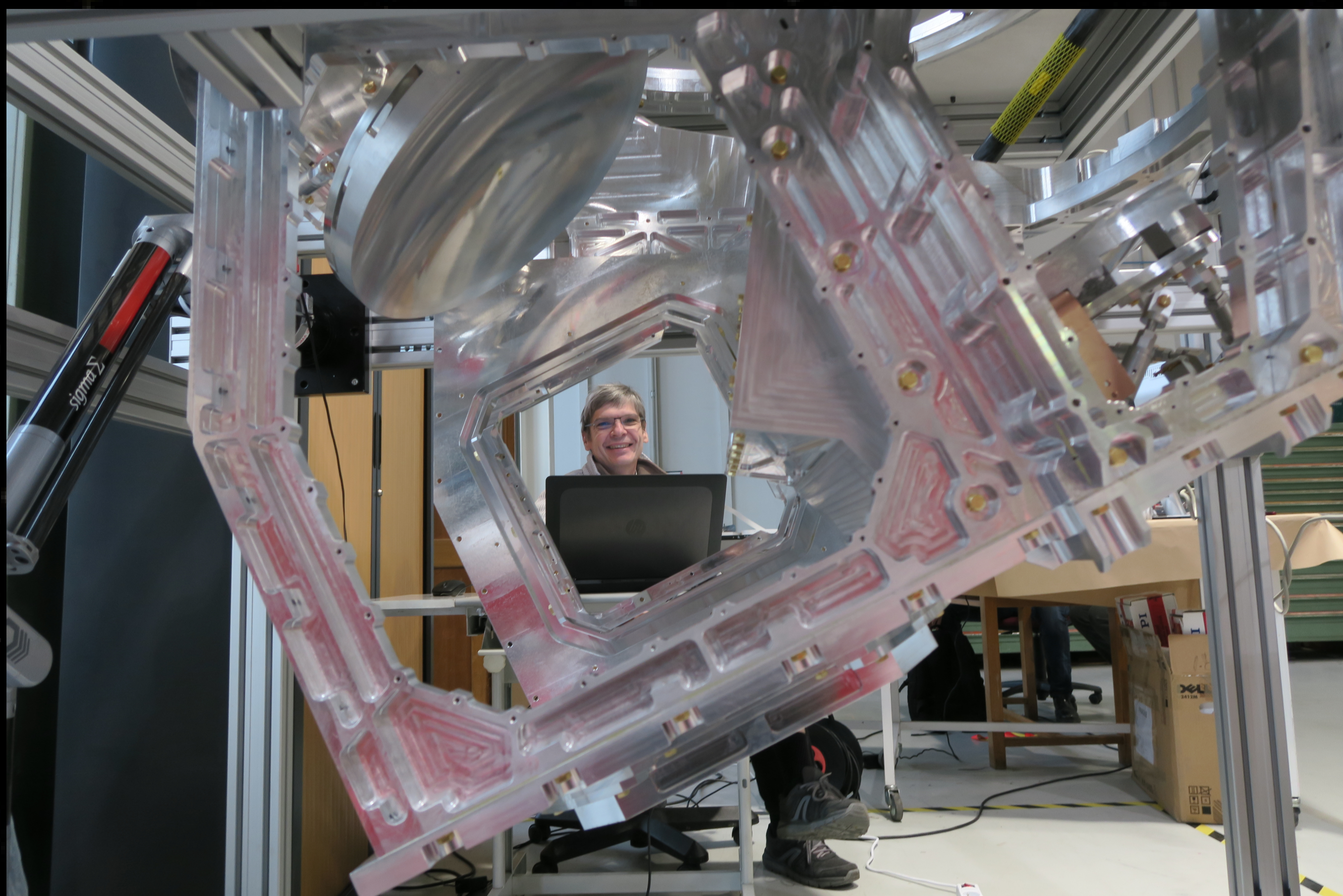


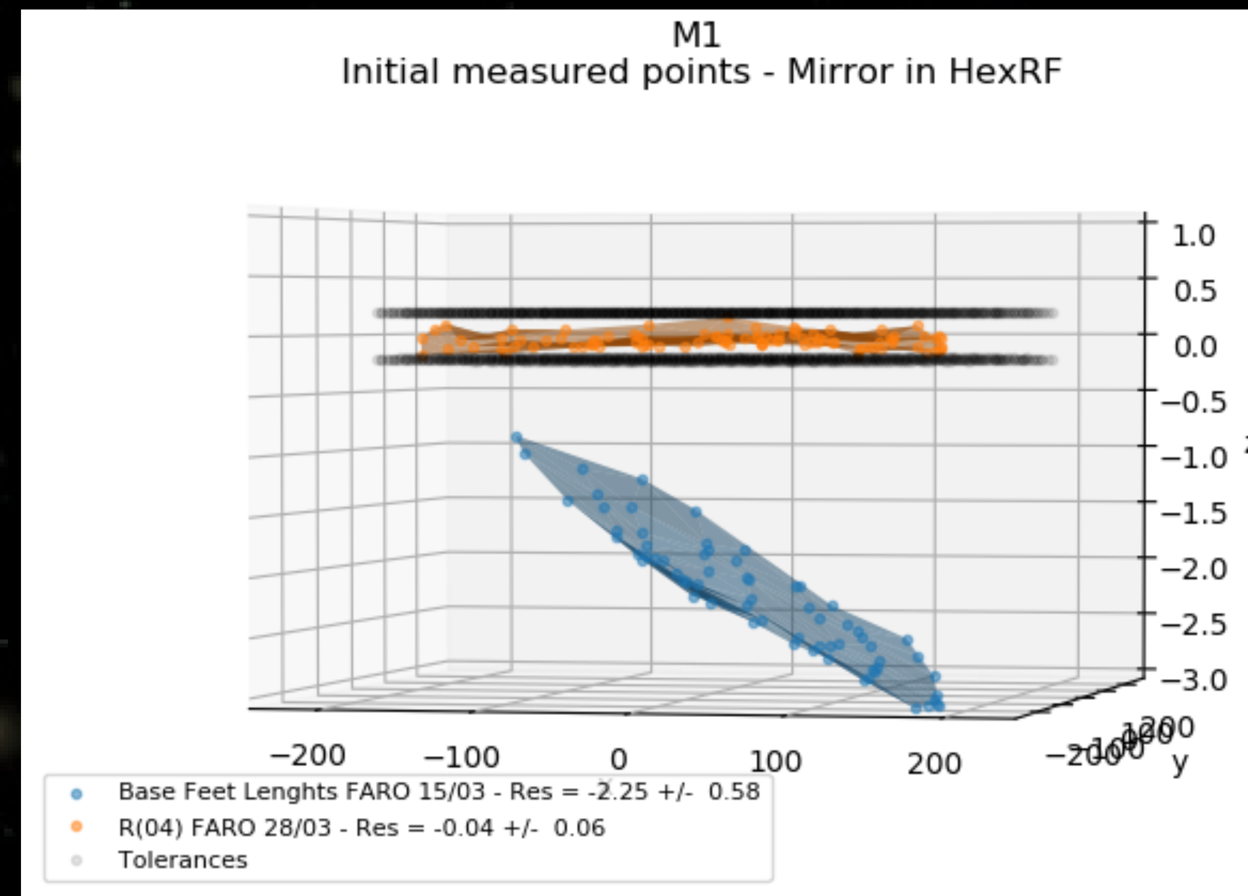
Yield: ~84% (array ref P87) - State of the Art



QUBIC Hardware

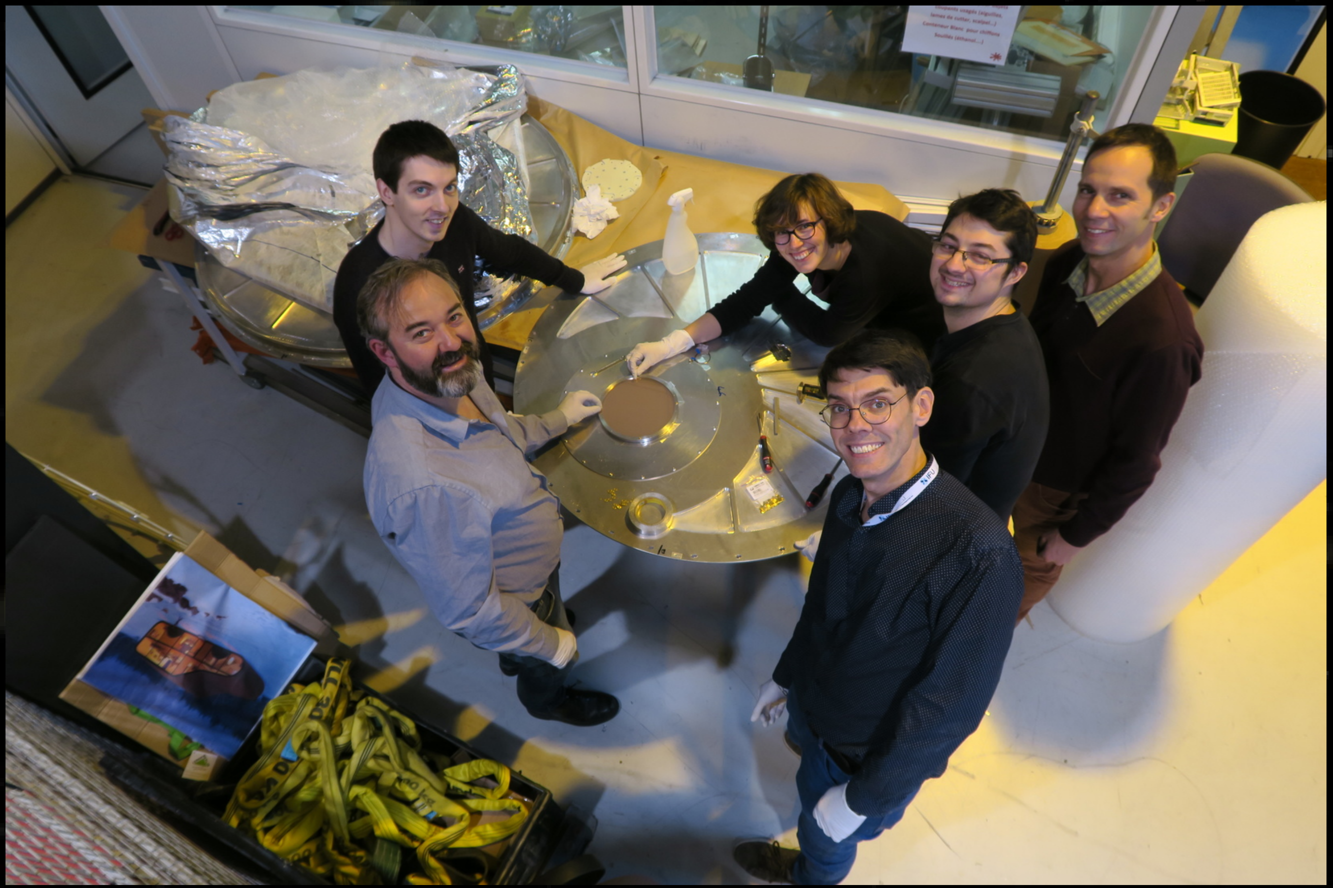
Optics box at 1K





Structure: APC
Mirrors + alignment: Milano, Roma, APC

QUBIC Hardware



Quasi-optical cryogenic components:
filters, Half-Wave-Plate, Polarizer
Designed and fabricated in Cardiff

QUBIC Hardware

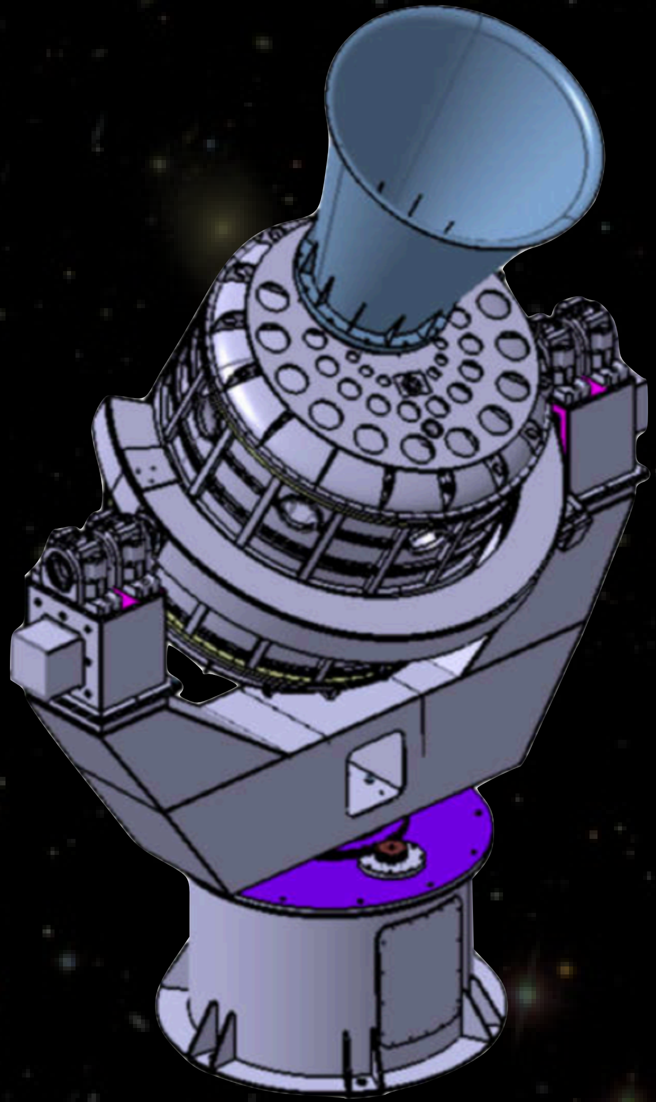
1K and 300mK He4 fridges - Manchester

More than 50 cycles of the 300mK fridges so far

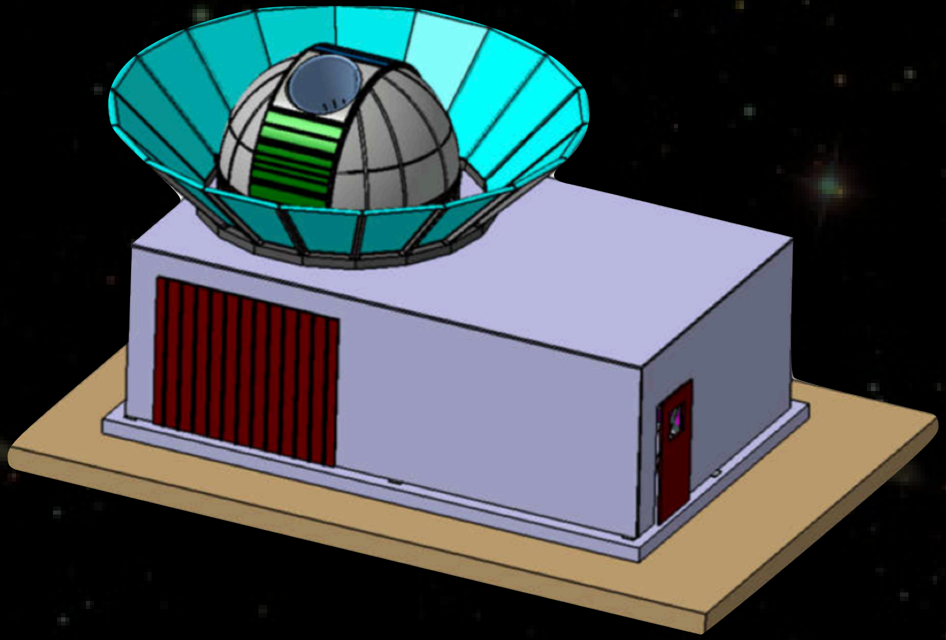
QUBIC Hardware

Site and Integration Hall
ITeDA, CNEA, Argentina

Mount:
GEMA, Argentina



Works in progress



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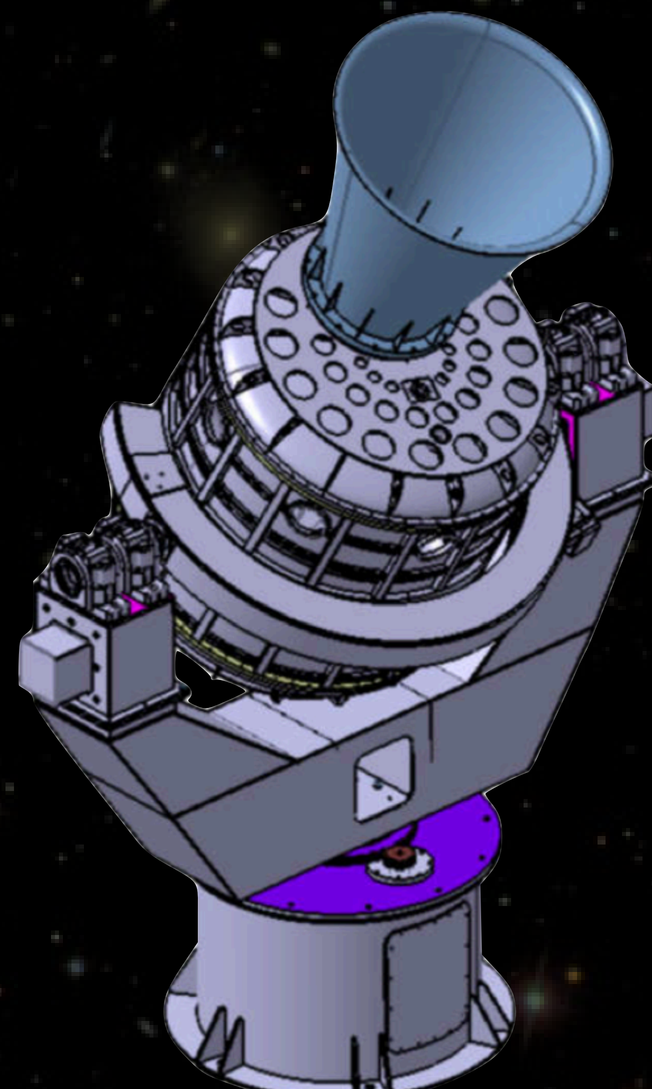

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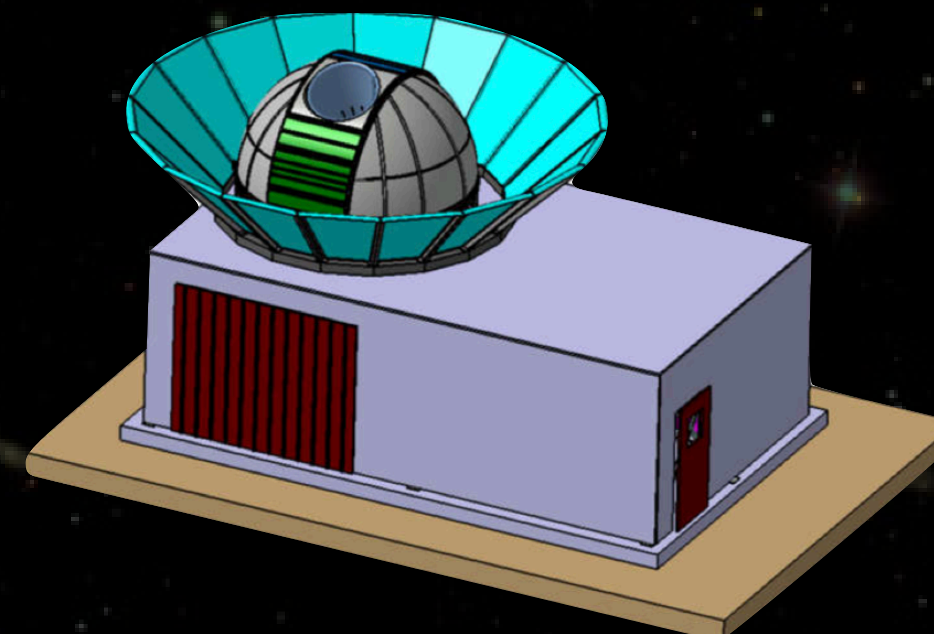


QUBIC Deployment Plan

<u>2018-2019 : at APC</u>

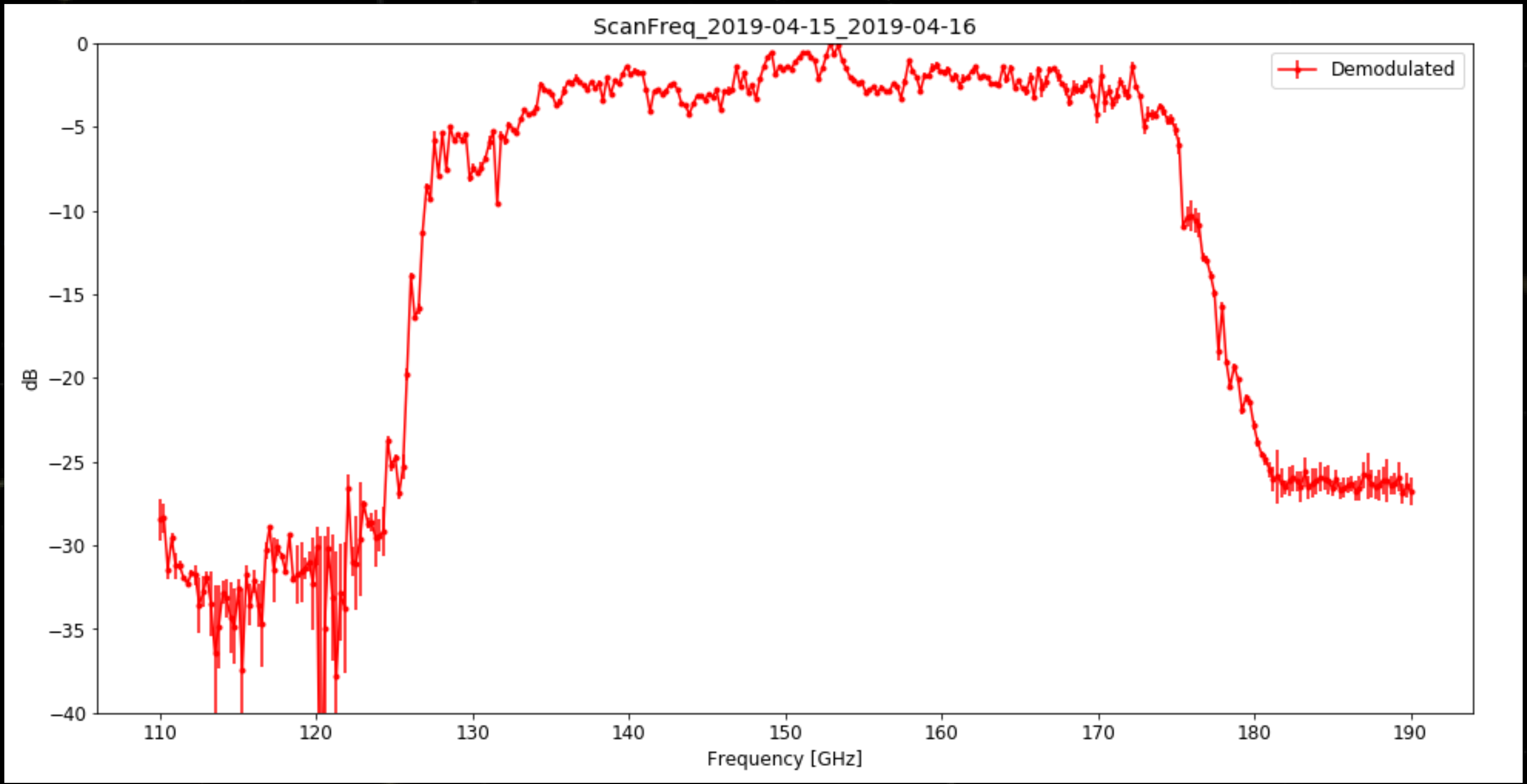
- Calibration on the way
- Technological Demonstrator (reduced QUBIC)
  - 1/4 focal plane, 64 horns, small mirrors

→

In-Lab demonstration of Bolometric Interferometry

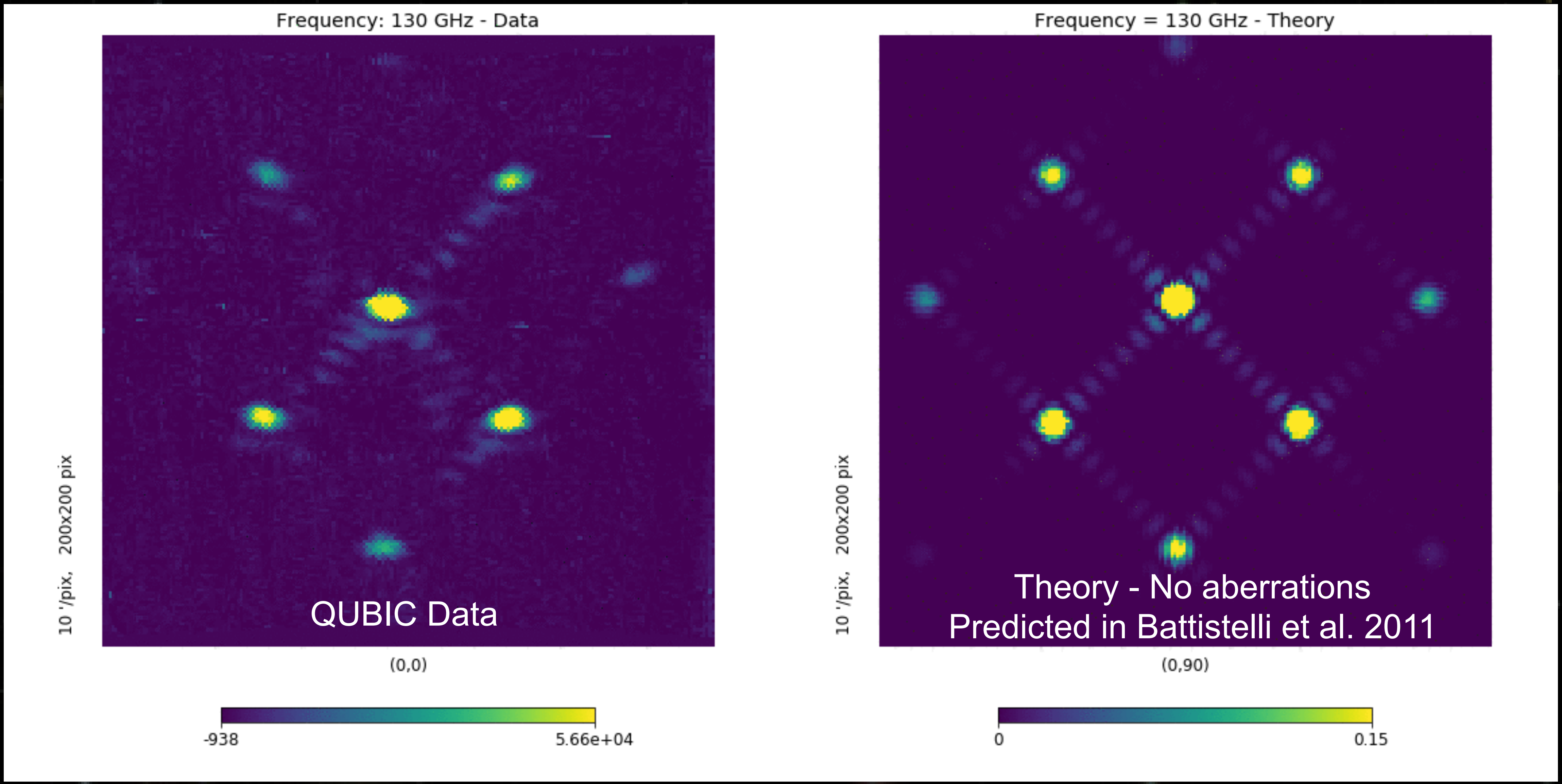
In-lab calibration results so far

- Bandwidth measurement: as expected



In-lab calibration results so far

- Synthesized beams: first measurement ever !



Frequency scaling is the basis of Spectro-Imaging
A possibility unique to Bolometric Interferometry to constrain foregrounds

In-lab calibration results so far

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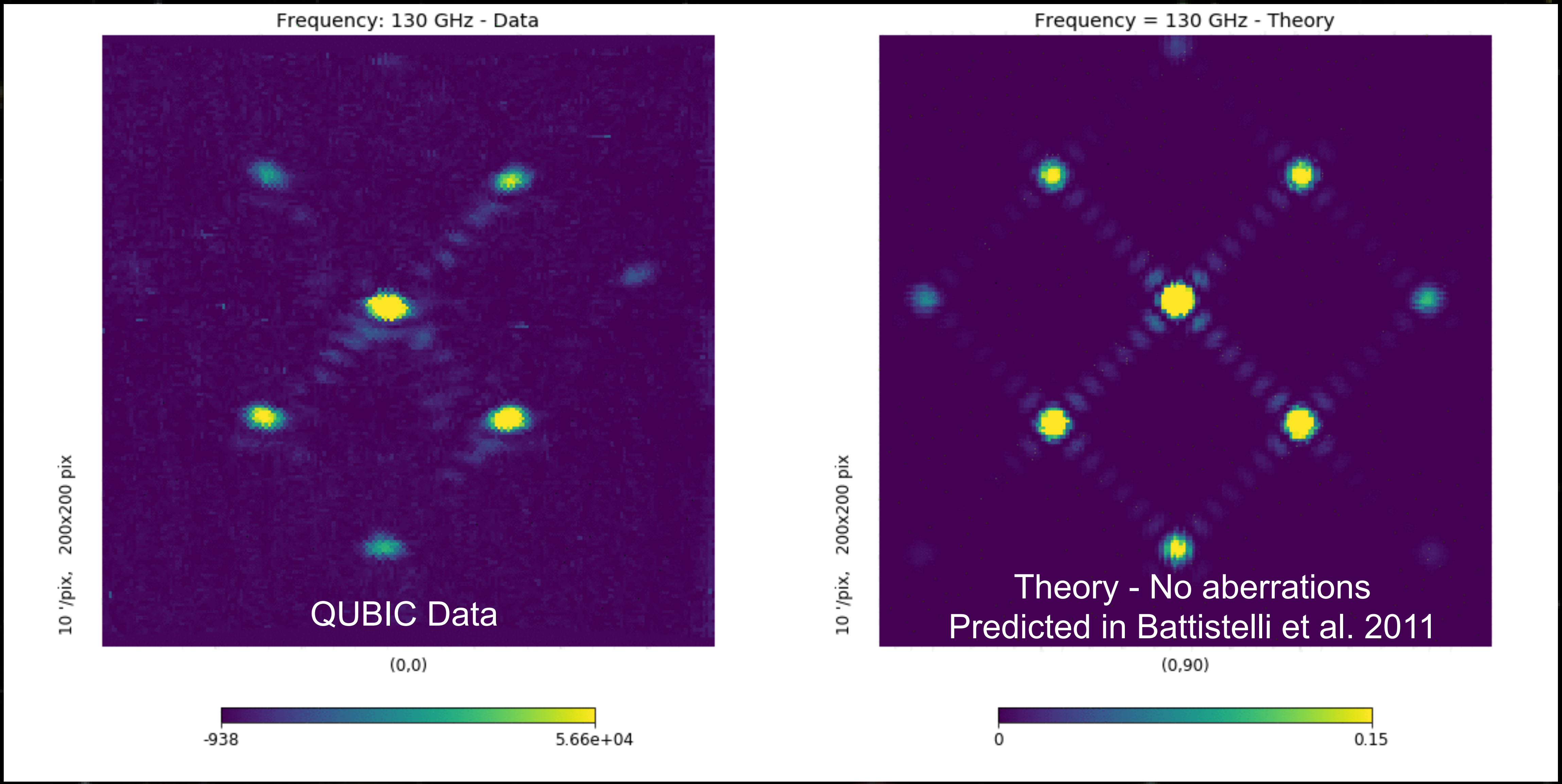

Frequency scaling is the basis of Spectro-Imaging
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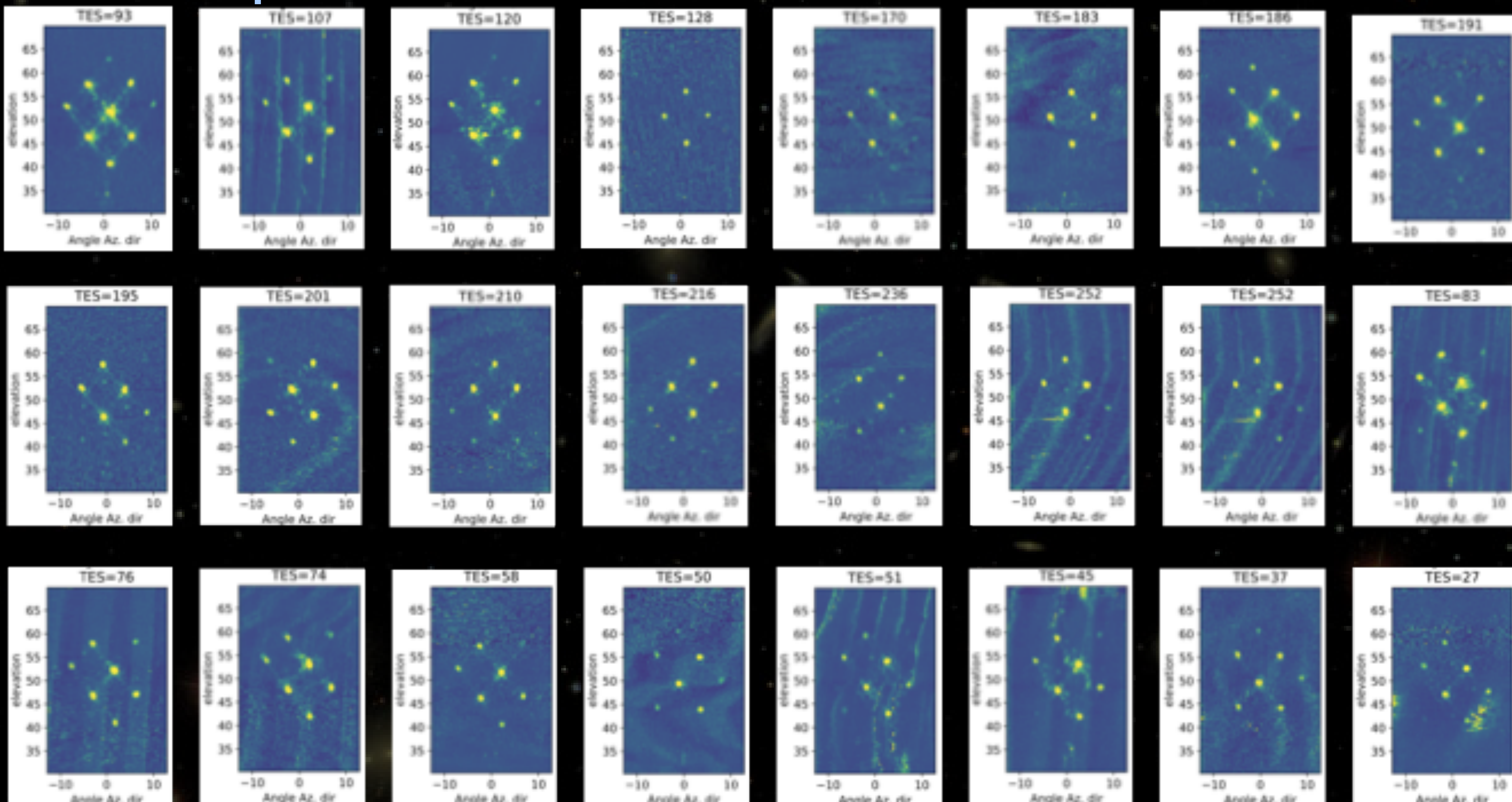
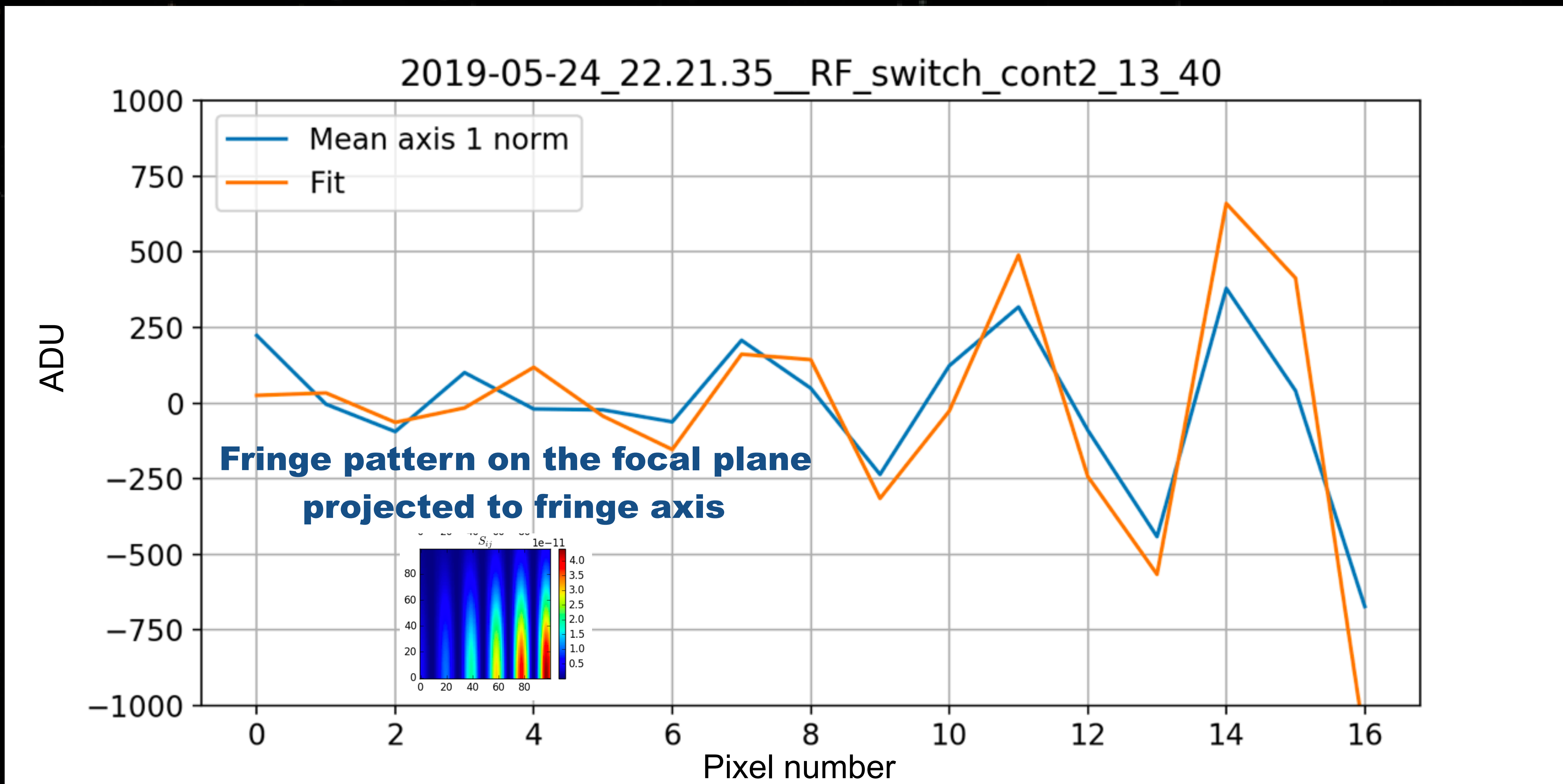
In-lab calibration results so far

- More pixels…



In-lab calibration results so far

- Individual baseline fringe pattern



A first step towards self-calibration !

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- Late 2019: Installation on site
- First Light with ¼ focal plane

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

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2021-… : QUBIC evolves towards Stage-IV

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

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→ 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
  - ★ Different and likely smaller instrumental 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 $\sigma(r)=0.001$

- QUBIC deployment is on the way:
  - ★ TD calibration ongoing at APC
  - ★ First light in Argentina late-2019
  - ★ Upgrade to Nominal Instrument in 2020

- Welcome to jump-in anytime !!!

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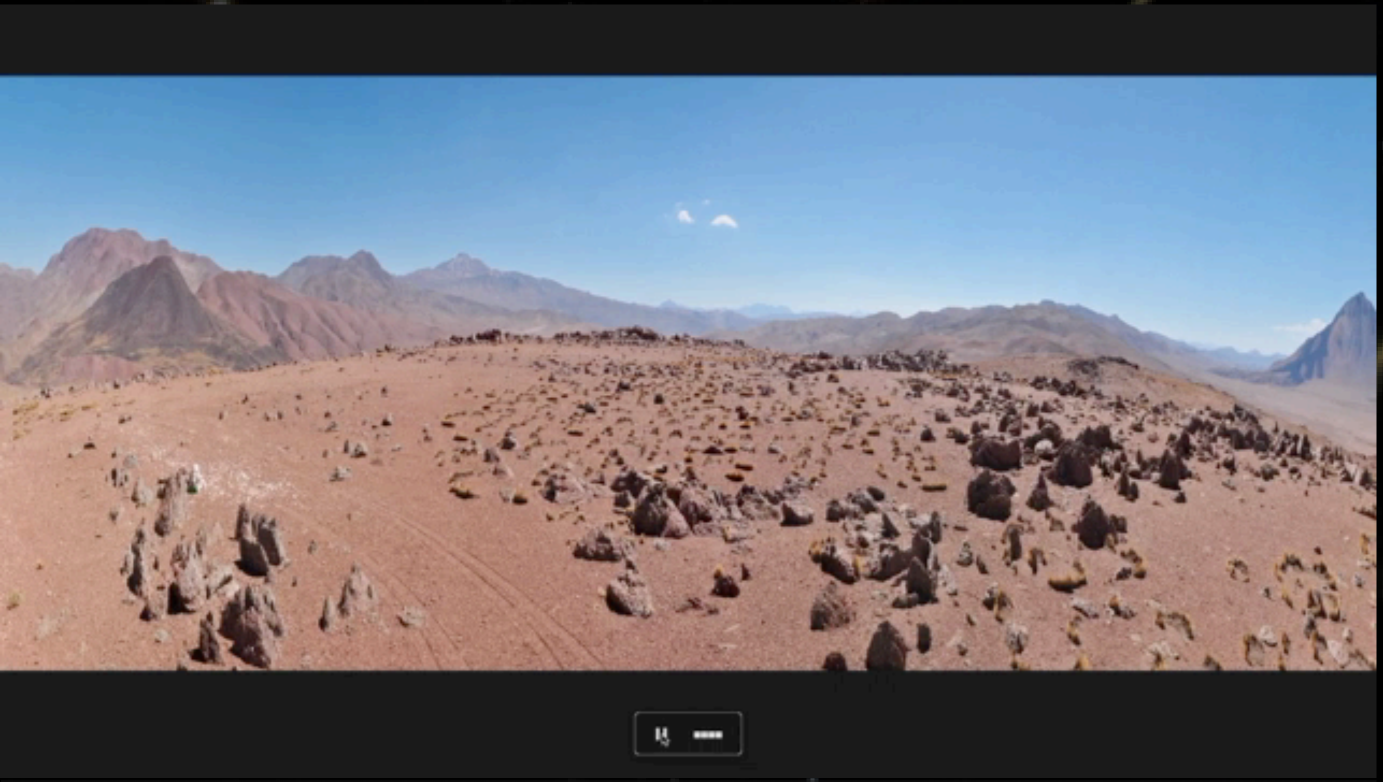
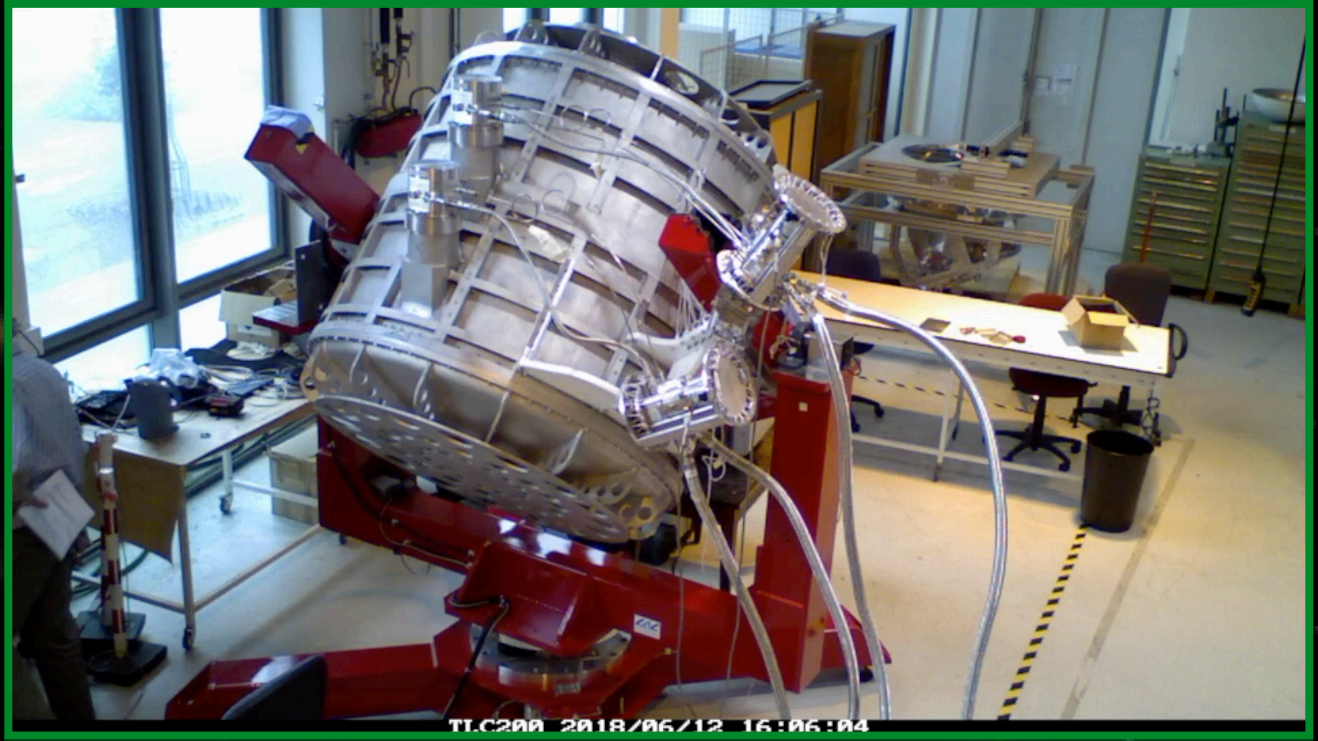
Thank you

View from the site



Integration timelapse (2018)

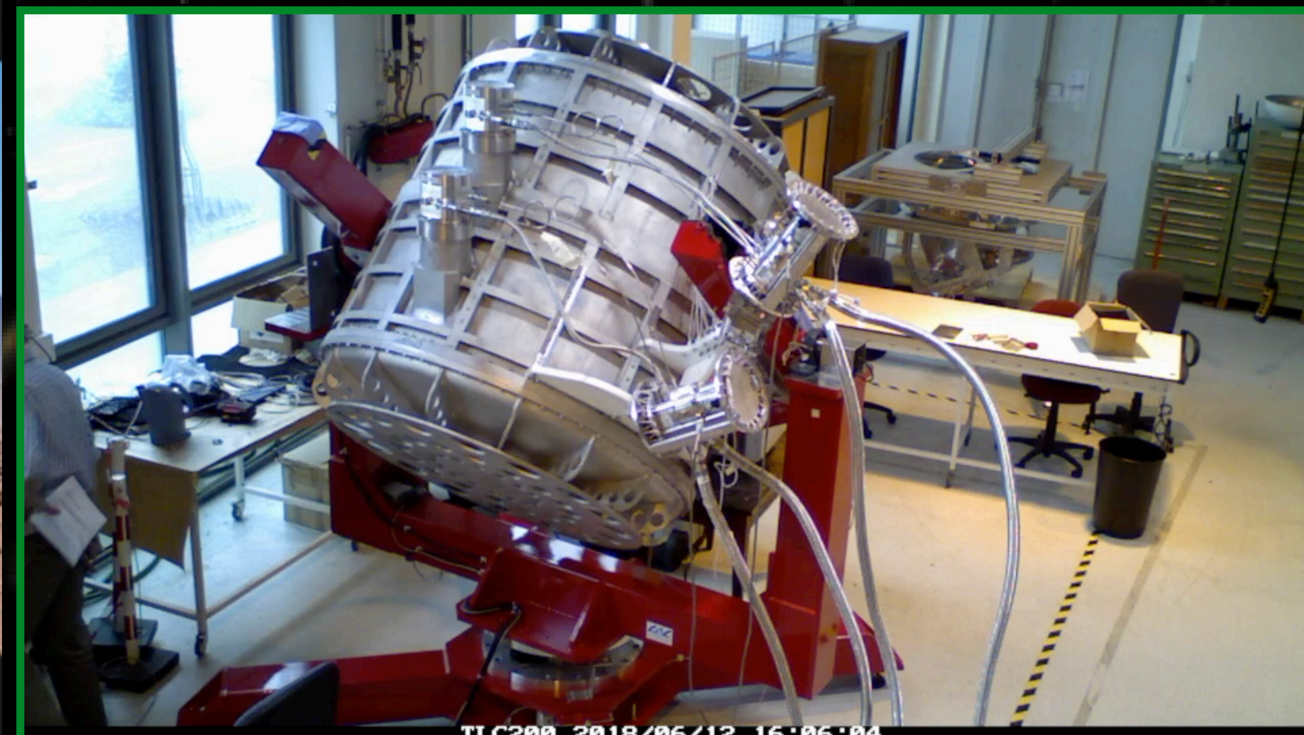


Exciting times ahead !!!

Thank you

View from the site

Integration timelapse (2018)



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