



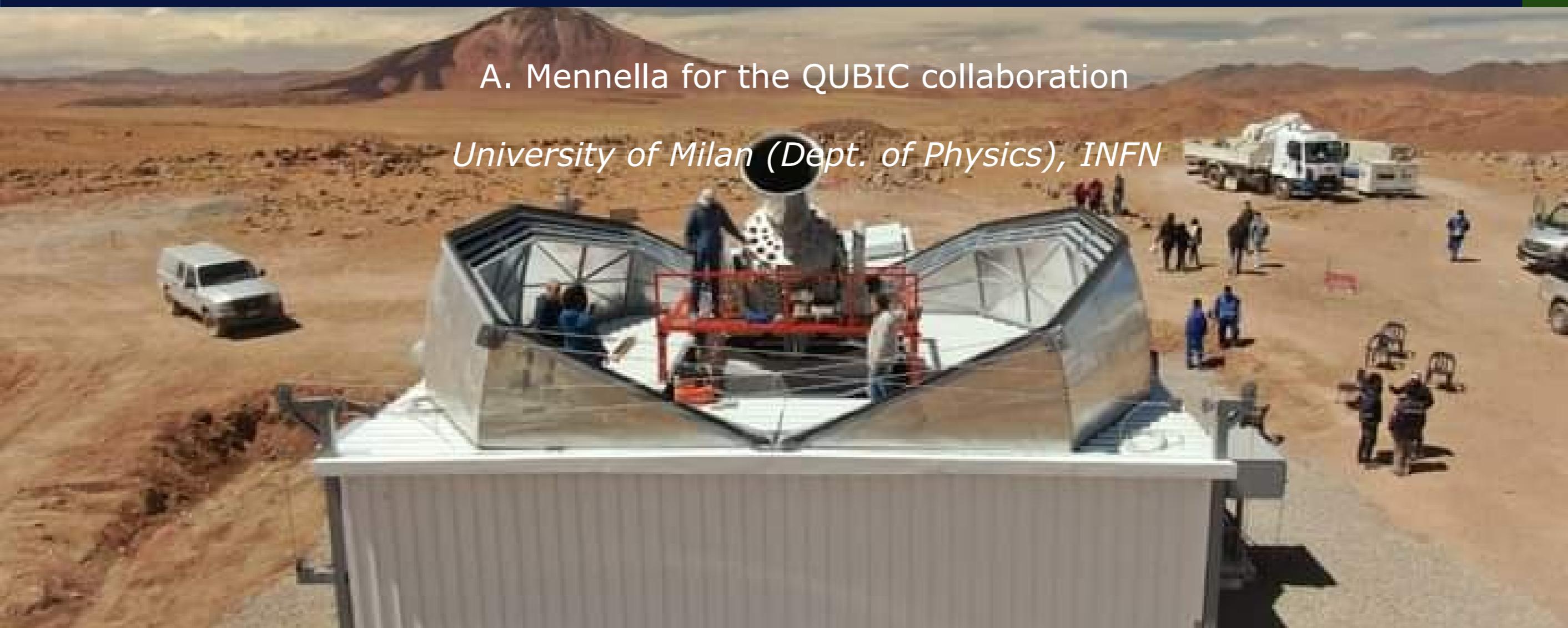
# Measuring the CMB primordial B-modes with Bolometric Interferometry

*status and future prospects of the QUBIC experiment*



A. Mennella for the QUBIC collaboration

*University of Milan (Dept. of Physics), INFN*



# QUBIC people

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P. Chanial	M. Gervasi	M. McCulloch	G. Polenta	L. Vacher
C. Chapron	M. Giard	L. Mele	D. Prêle	F. Voisin
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A. Coppolecchia	M. González	N. Miròn-Granese	E. Rasztoky	A. Zullo



# Collaboration and funding agencies

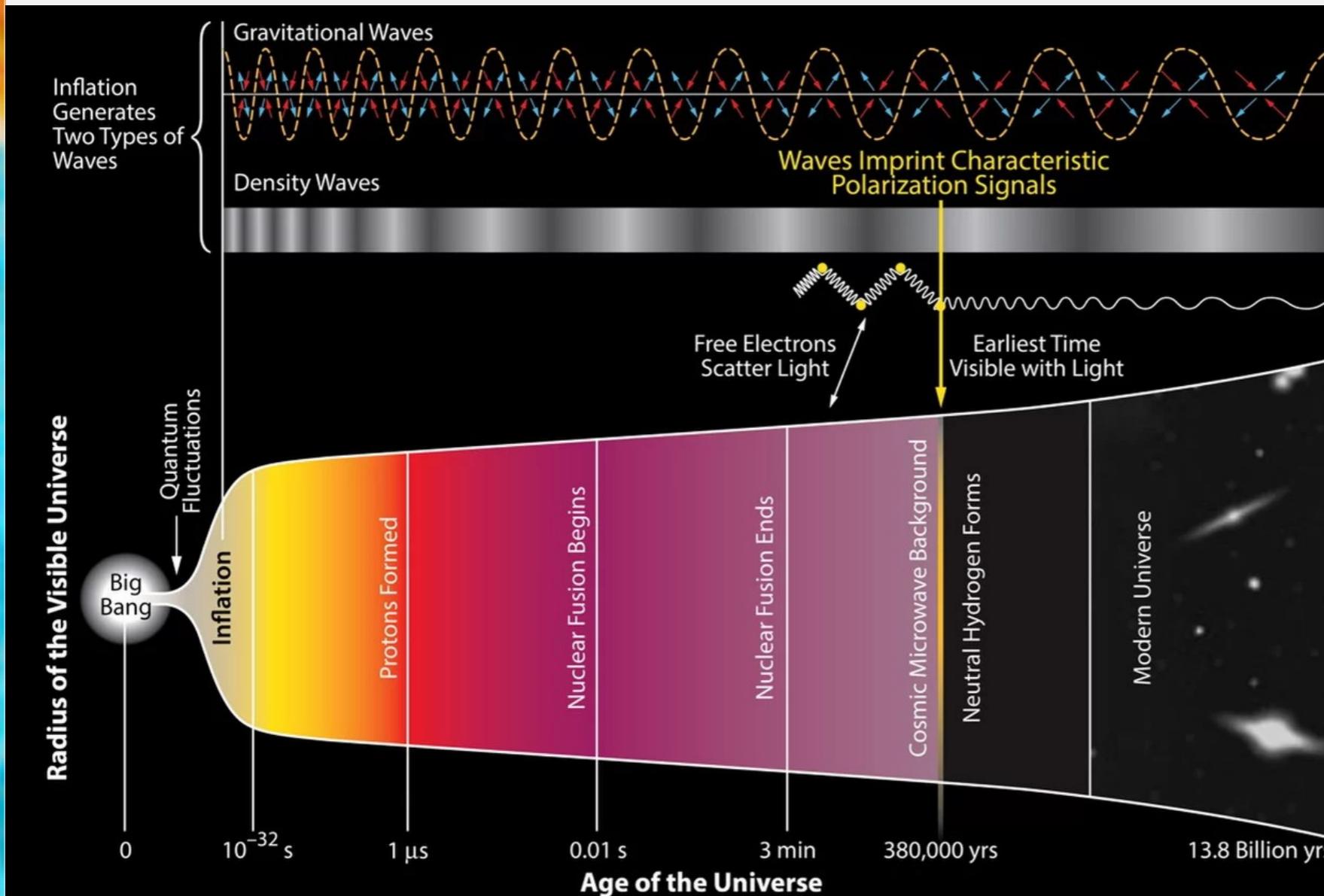
APC Paris, France  
CSNSM, France  
IAS Orsay, France  
IEF Orsay, France  
IRAP Toulouse, France  
LAL Orsay, France  
Università di Milano Bicocca  
INFN sezione di Milano Bicocca, Italy  
Università degli Studi di Milano, Italy  
INFN sezione di Milano, Italy  
Università La Sapienza, Roma, Italy  
INFN sezione di Roma, Italy  
Università di Tor Vergata, Roma, Italy  
INFN sezione di Roma2, 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 Ciencias Astronómicas y Geofisicas, Argentina  
Centro Atómico Bariloche and Istituto Balseiro, Argentina  
Instituto de Tecnologias en Detección y Astropartículas, Argentina  
Instituto Argentino de Radioastronomía, Argentina



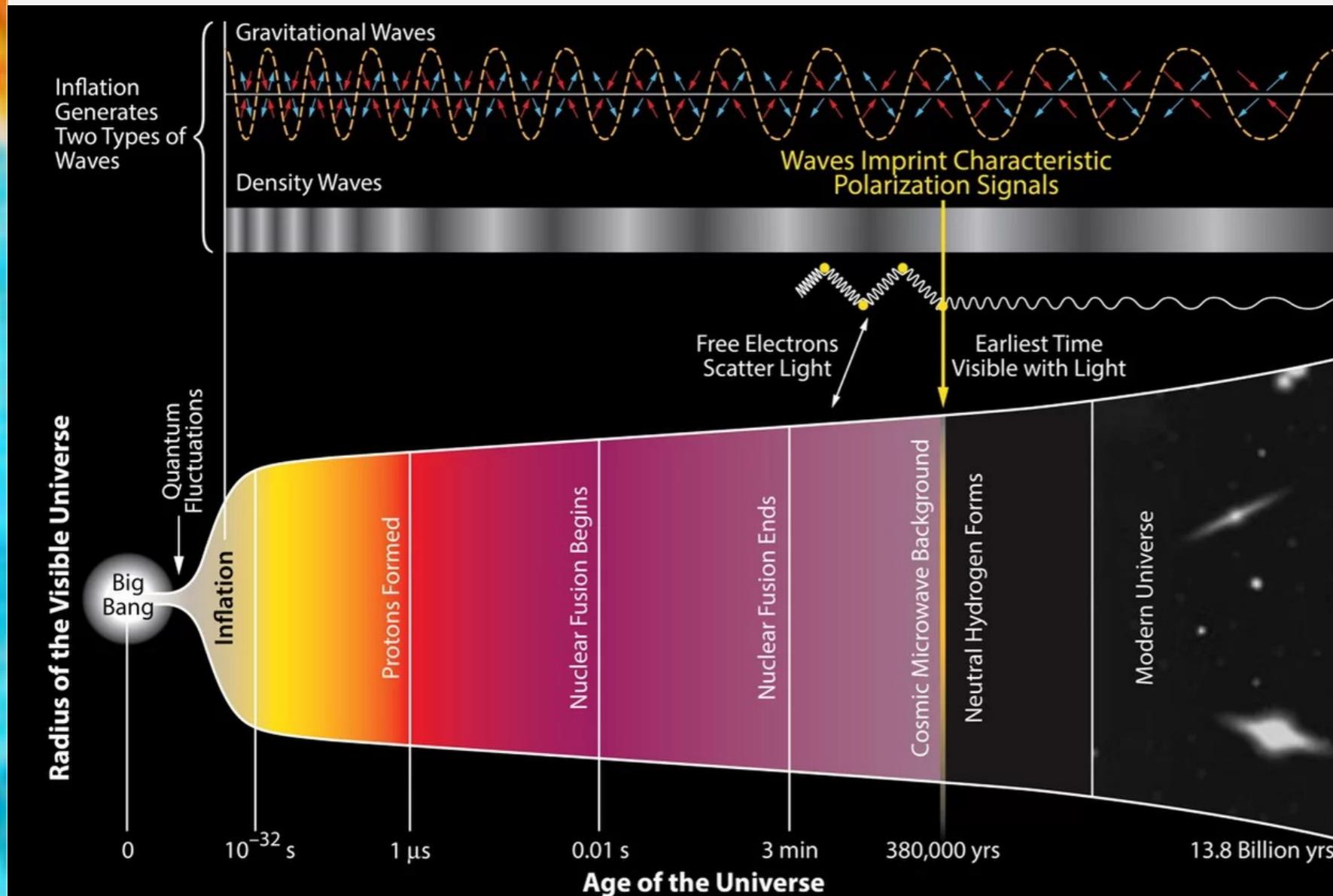
## Funding agencies



# Inflation and primordial gravitational waves



# Inflation and primordial gravitational waves

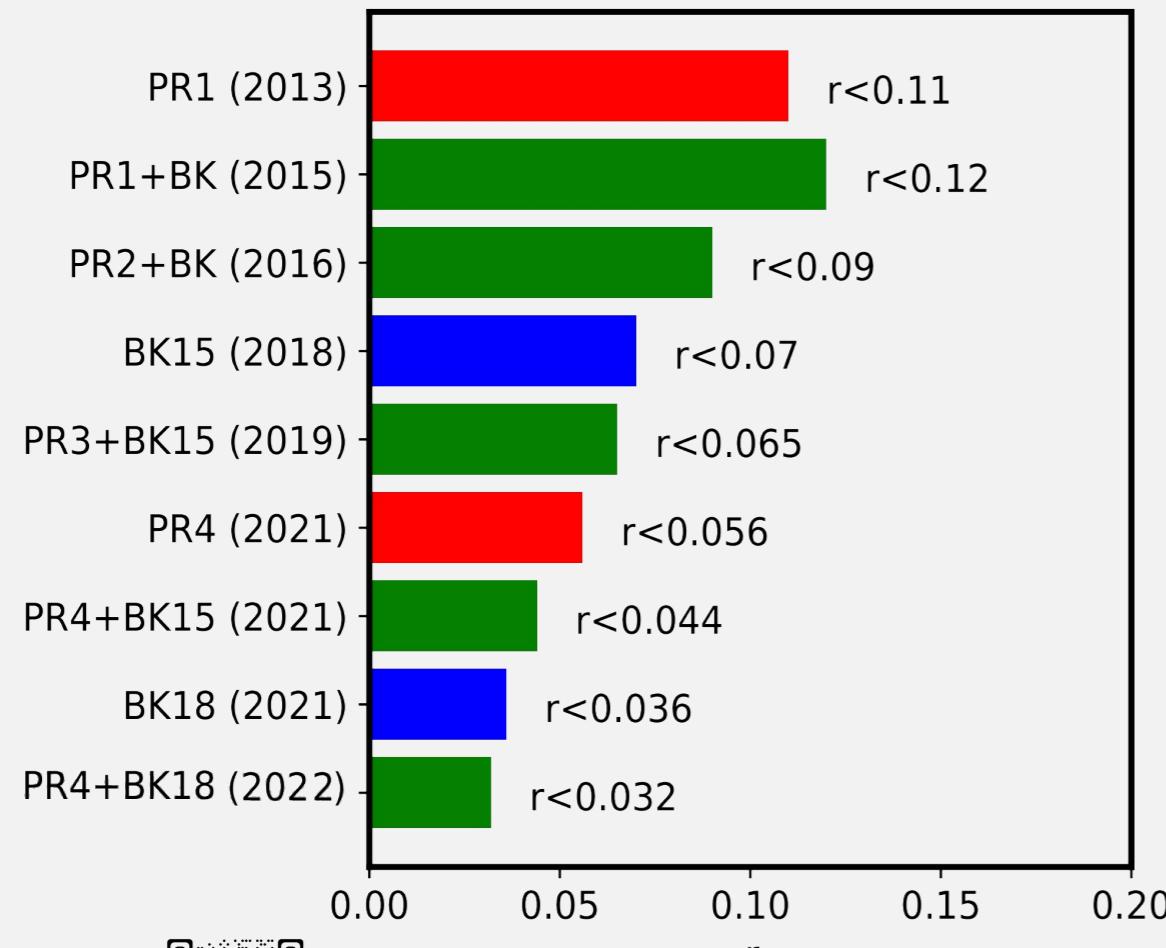


The inflationary paradigm predicts the existence of both scalar and tensor perturbations.

The amplitude of tensor perturbation is poorly constrained and depends on the assumed potential of the inflaton field

**This amplitude is characterized by the “tensor-to-scalar” ratio parameter,  $r$**

# Measurements state-of-the-art



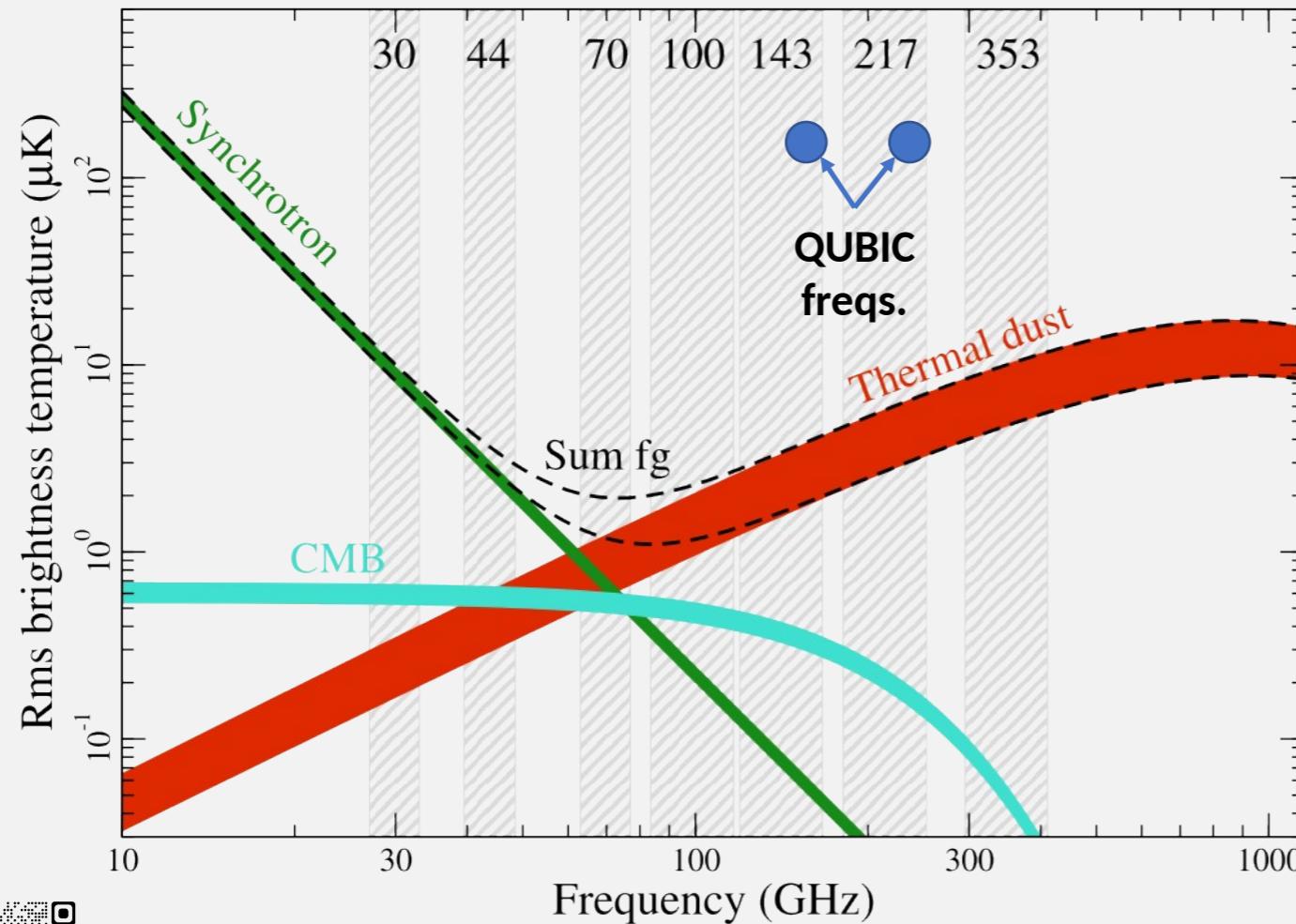
**QUBIC goal:  $r < 0.015$**

Measurements require high sensitivity  
but, especially:

- Control of instrumental systematic effects
- Control of astrophysical foregrounds (synchrotron and dust emissions, gravitational lensing)



# Measurements state-of-the-art



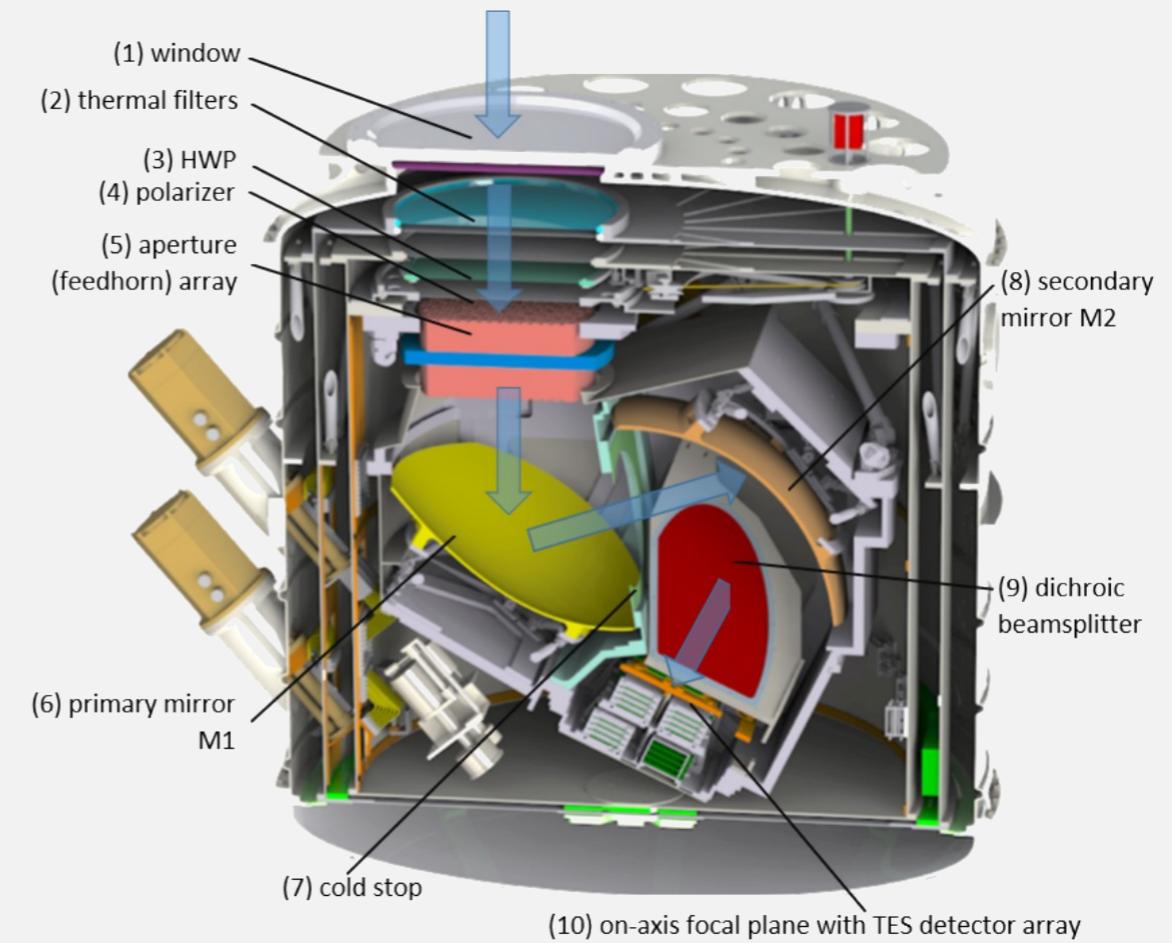
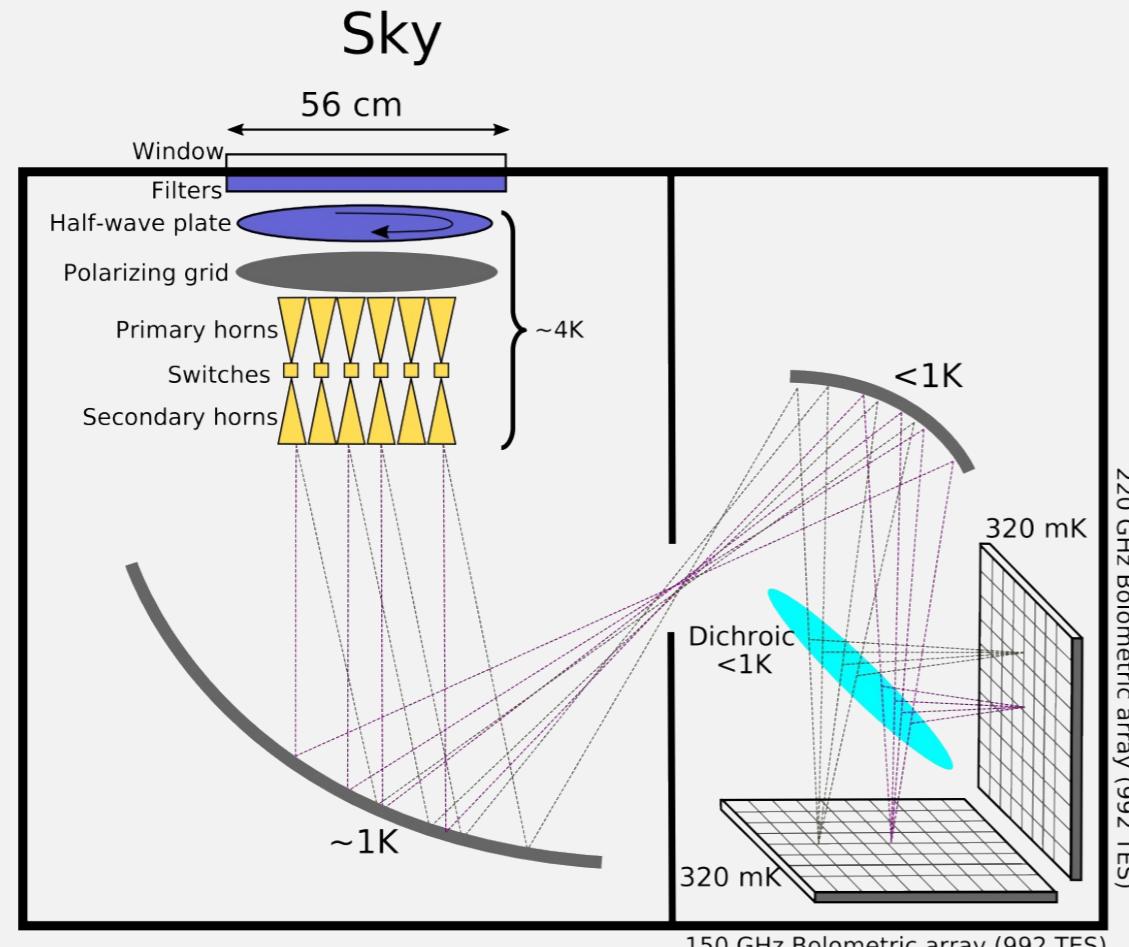
Planck collaboration et al, 2015

## QUBIC frequencies

- QUBIC will observe in a small patch of the sky relatively “clean” of foregrounds
- Dust contamination will be evaluated measuring at two frequencies and exploiting existing data like Planck



# QUBIC in a nutshell: the instrument



# QUBIC in a nutshell: the instrument

Class

## Two prototypes

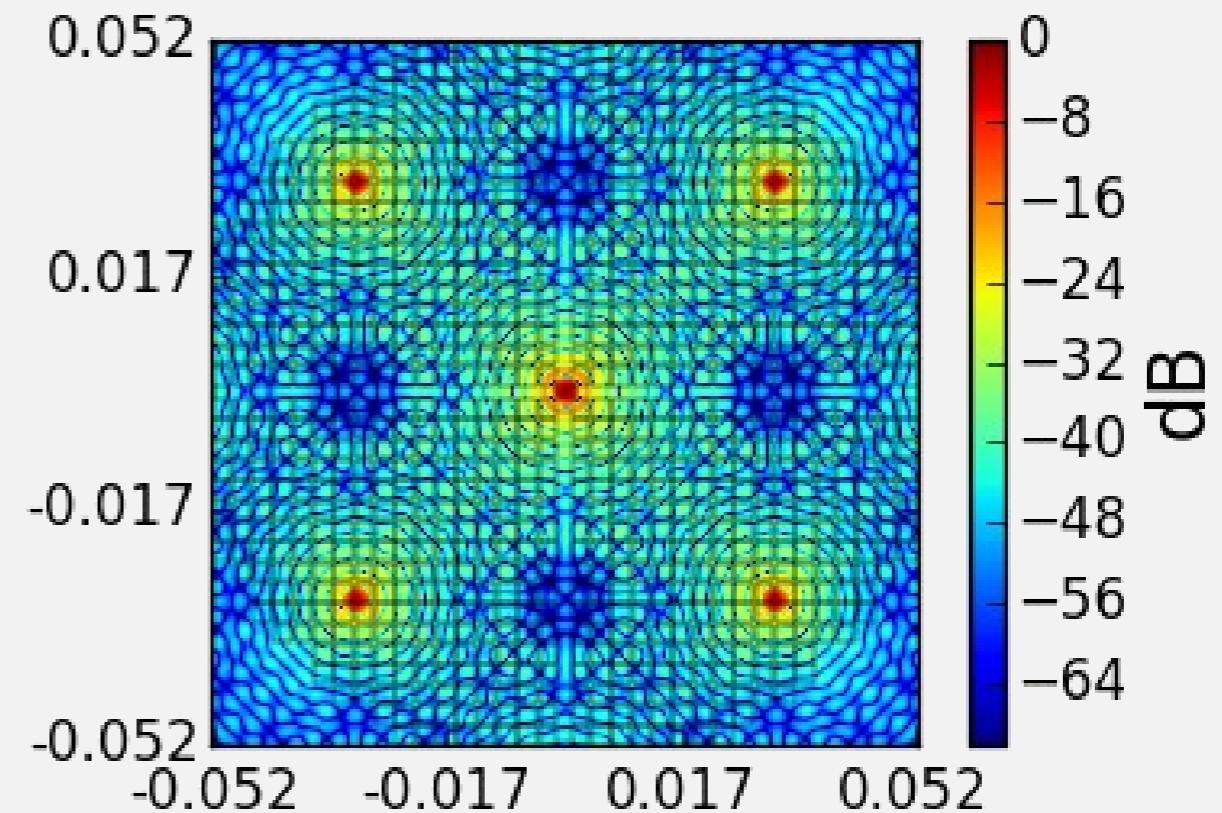
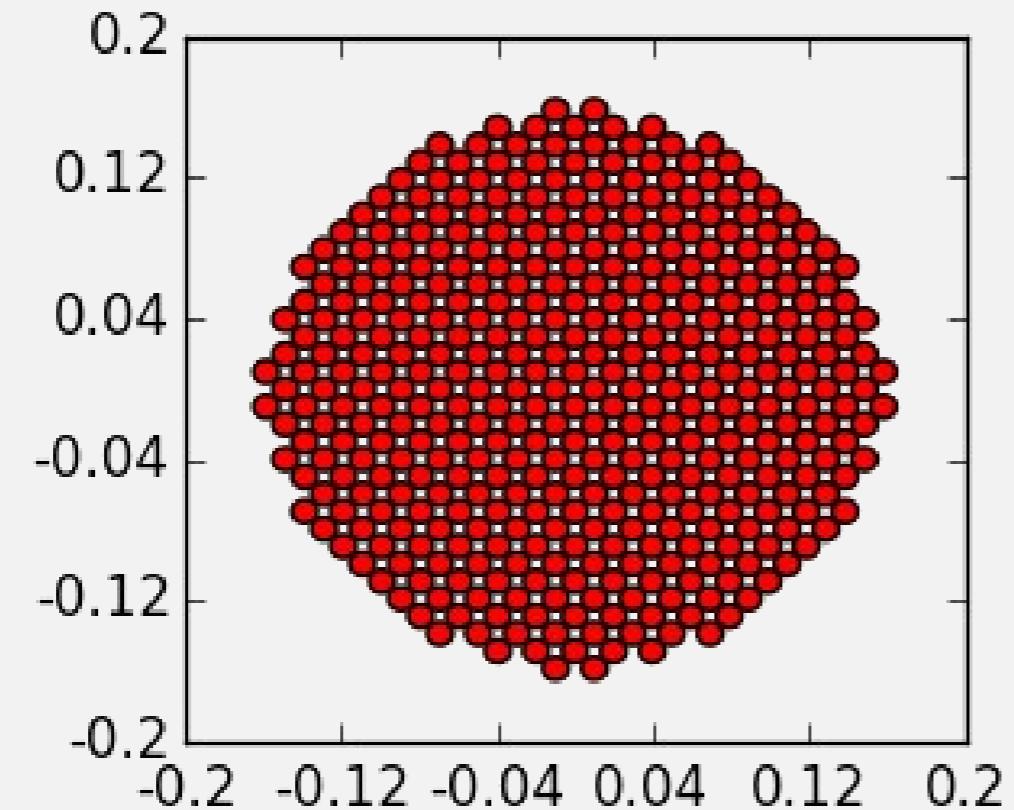
- ***Technological demonstrator (TD):***
  - 64+64 horns, smaller mirrors, single focal plane of 256 TES detectors at 150 GHz
  - Demonstration of bolometric interferometry with sky measurements
- ***Final instrument (FI):***
  - 400+400 horns, larger mirrors, two focal planes 992+992 TES detectors at 150 and 220 GHz
  - Tensor-to-scalar ratio and foregrounds

(10) on-axis focal plane with TES detector array



# QUBIC in a nutshell: the measurement

Response to a point source in the far field

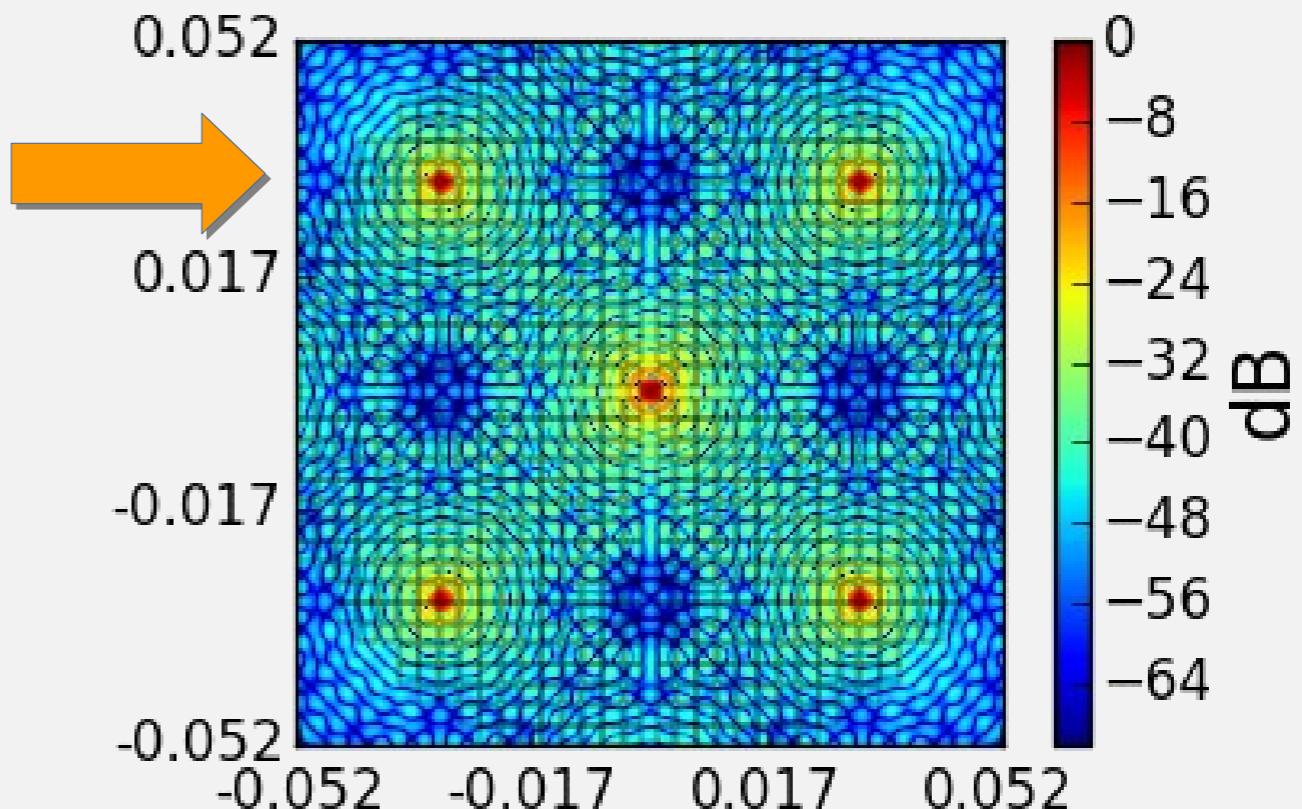


# QUBIC in a nutshell: the measurement

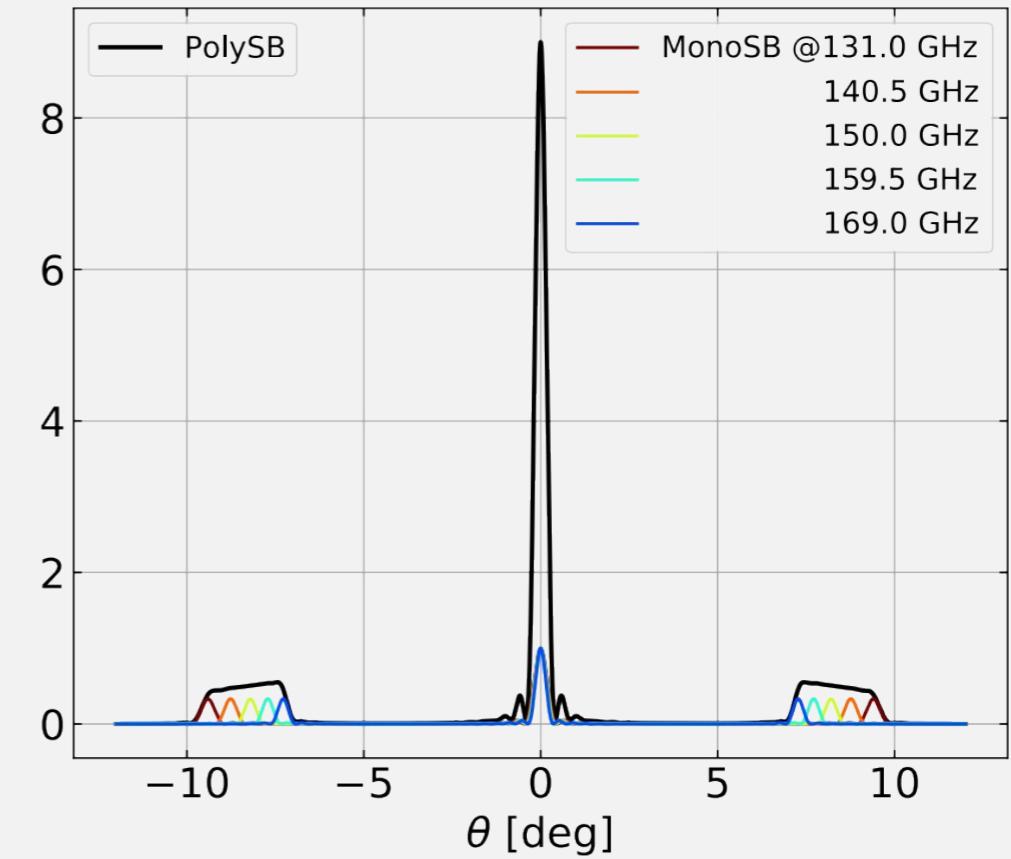
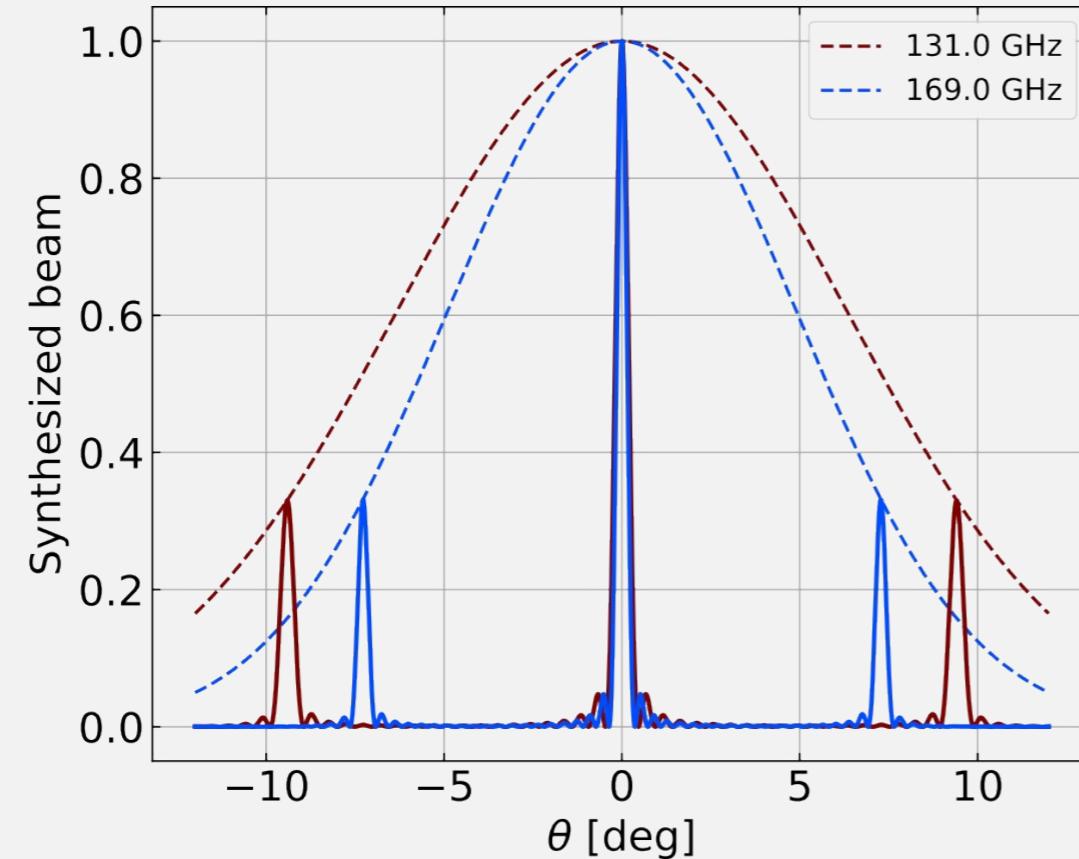
Response to a point source in the far field

Synthetic beam

The knowledge of the synthetic beam allows one to use the same data analysis algorithms used for conventional imagers



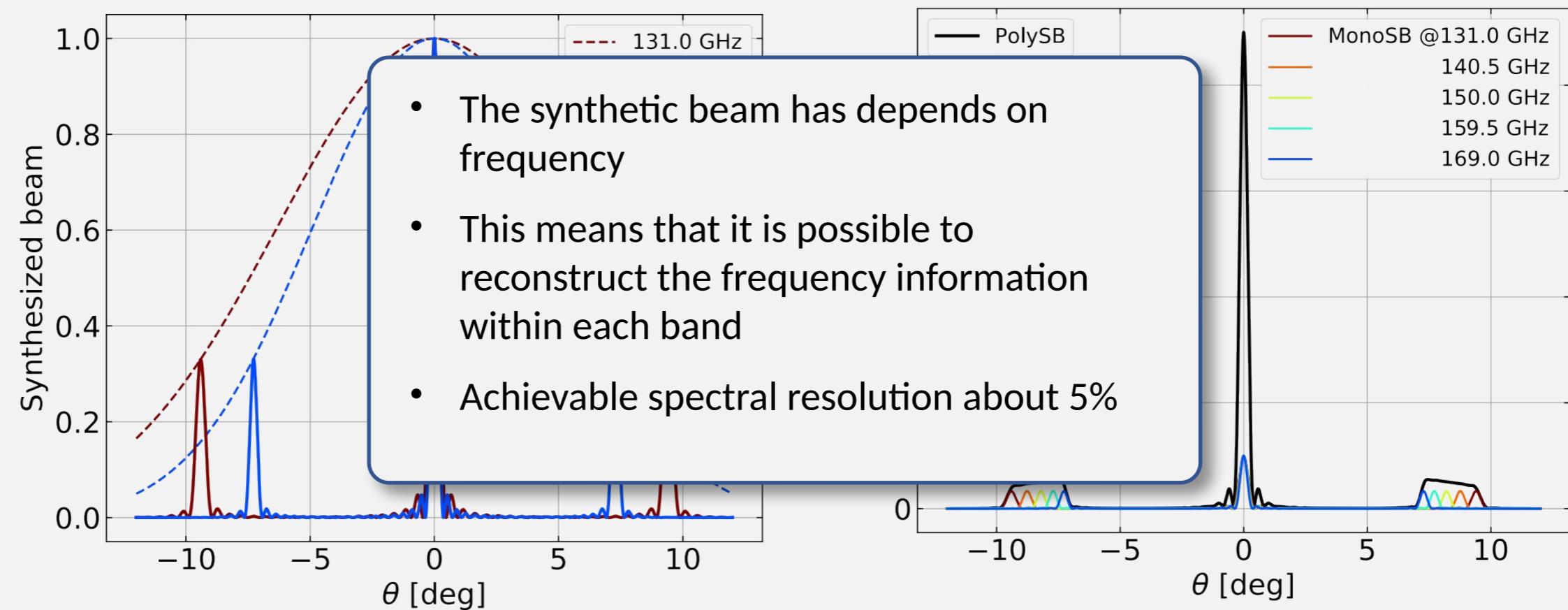
# QUBIC in a nutshell: spectral imaging



QUBIC Collaboration, 2022



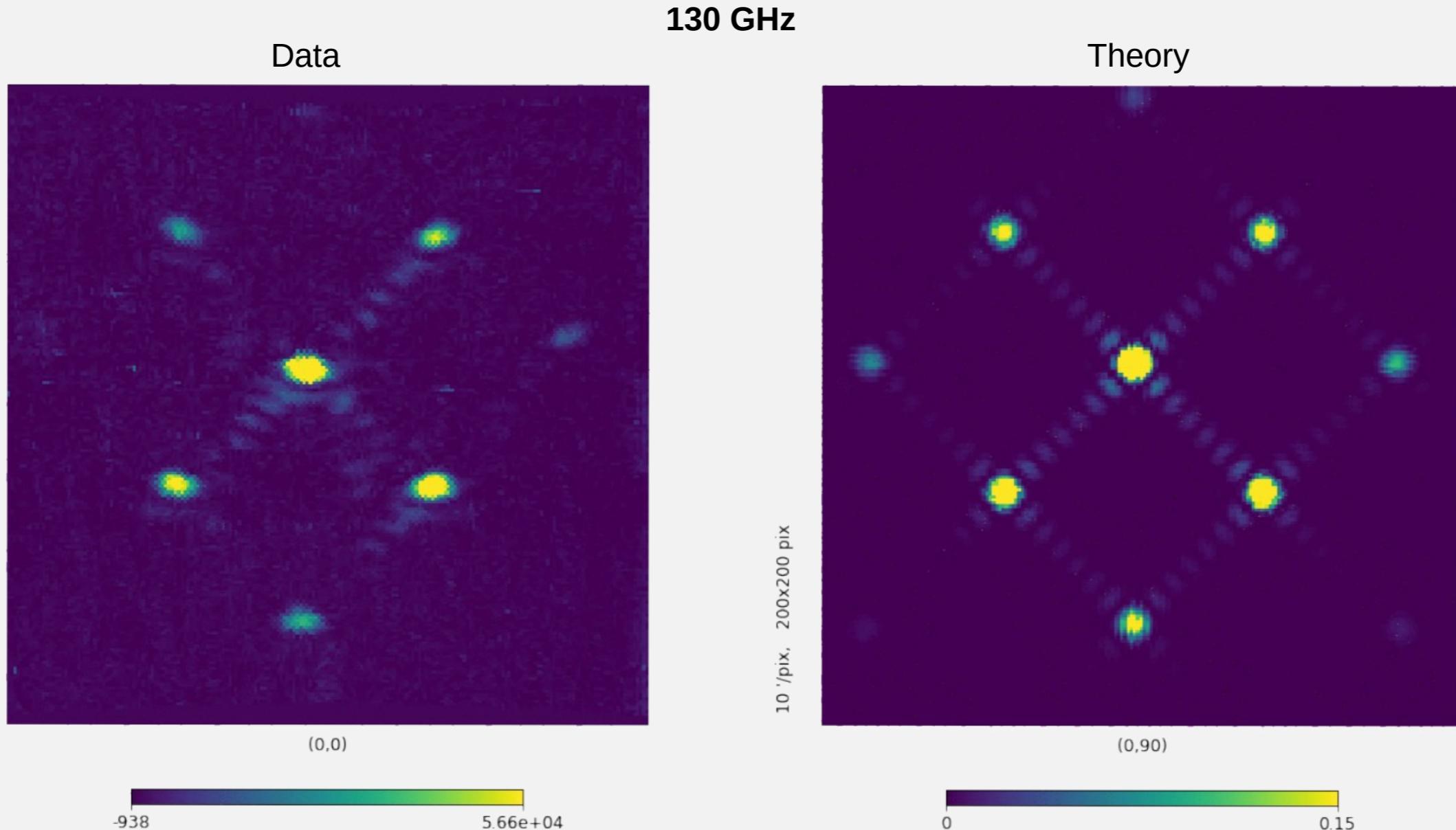
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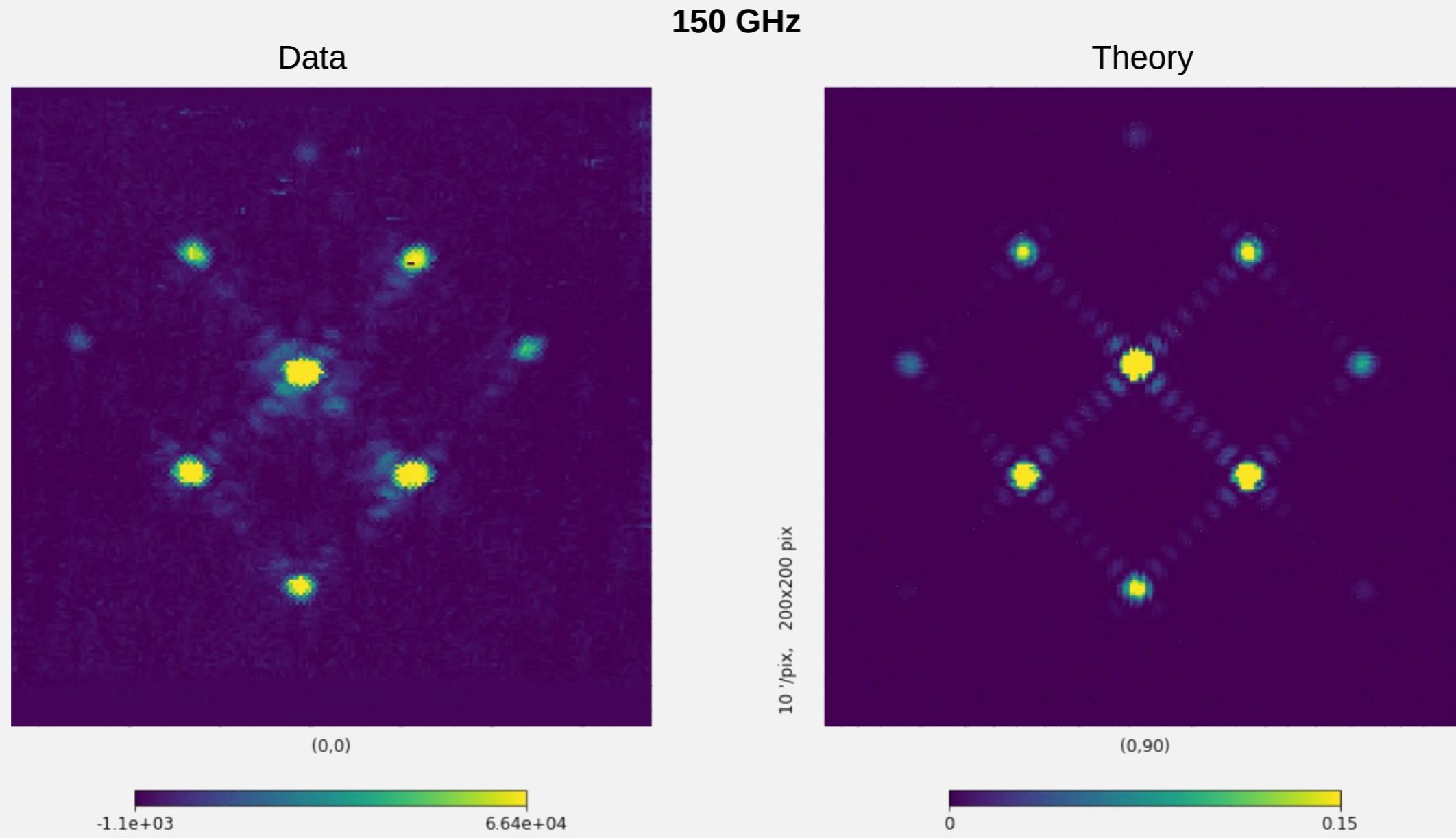
QUBIC Collaboration, 2022



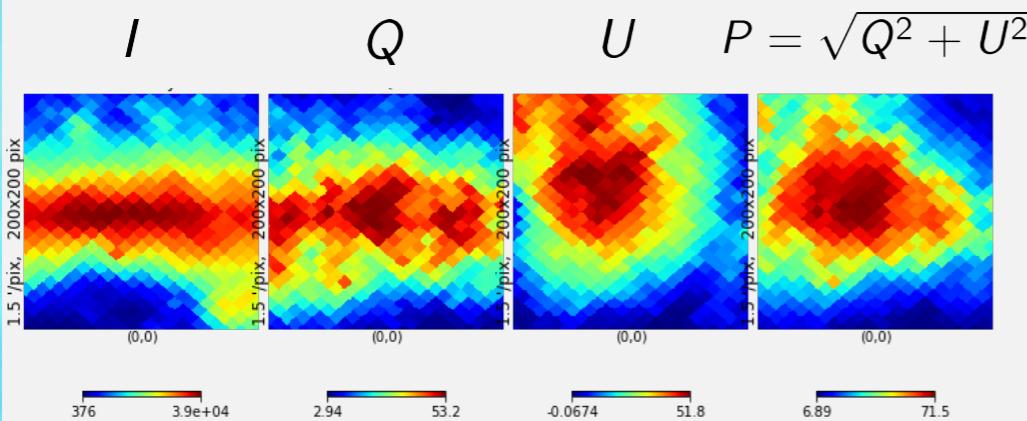
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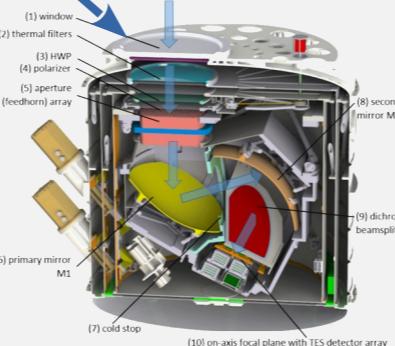
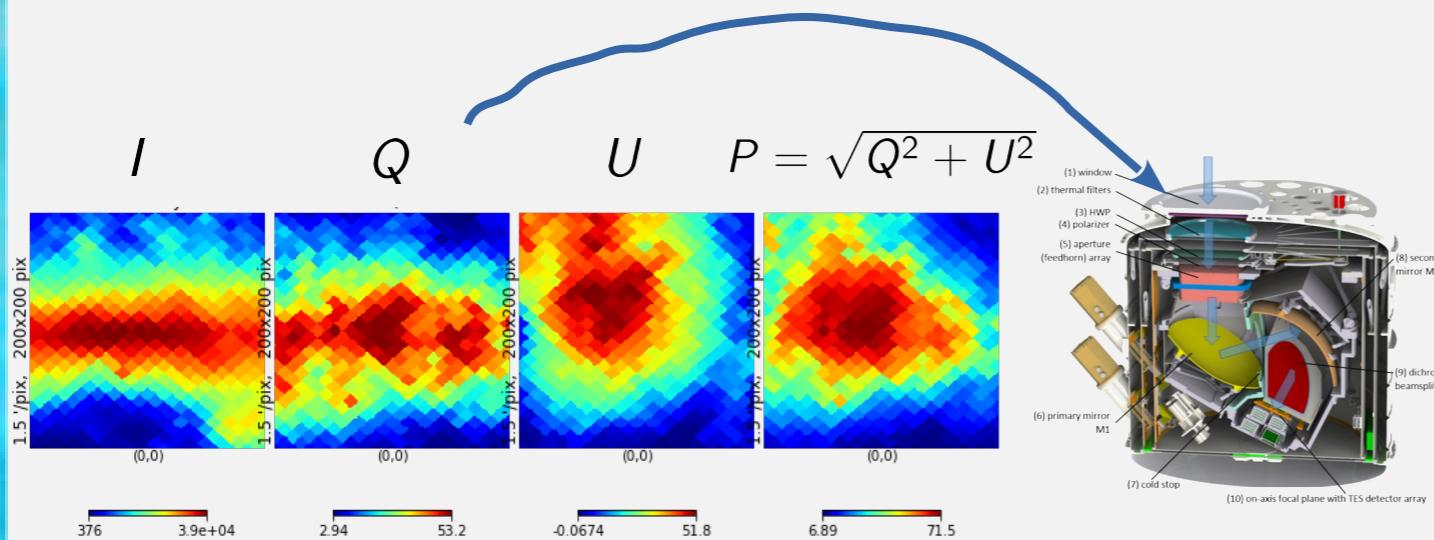
# QUBIC in a nutshell: spectral imaging



# “True sky” in a patch close to the Galactic center in the 150 GHz band

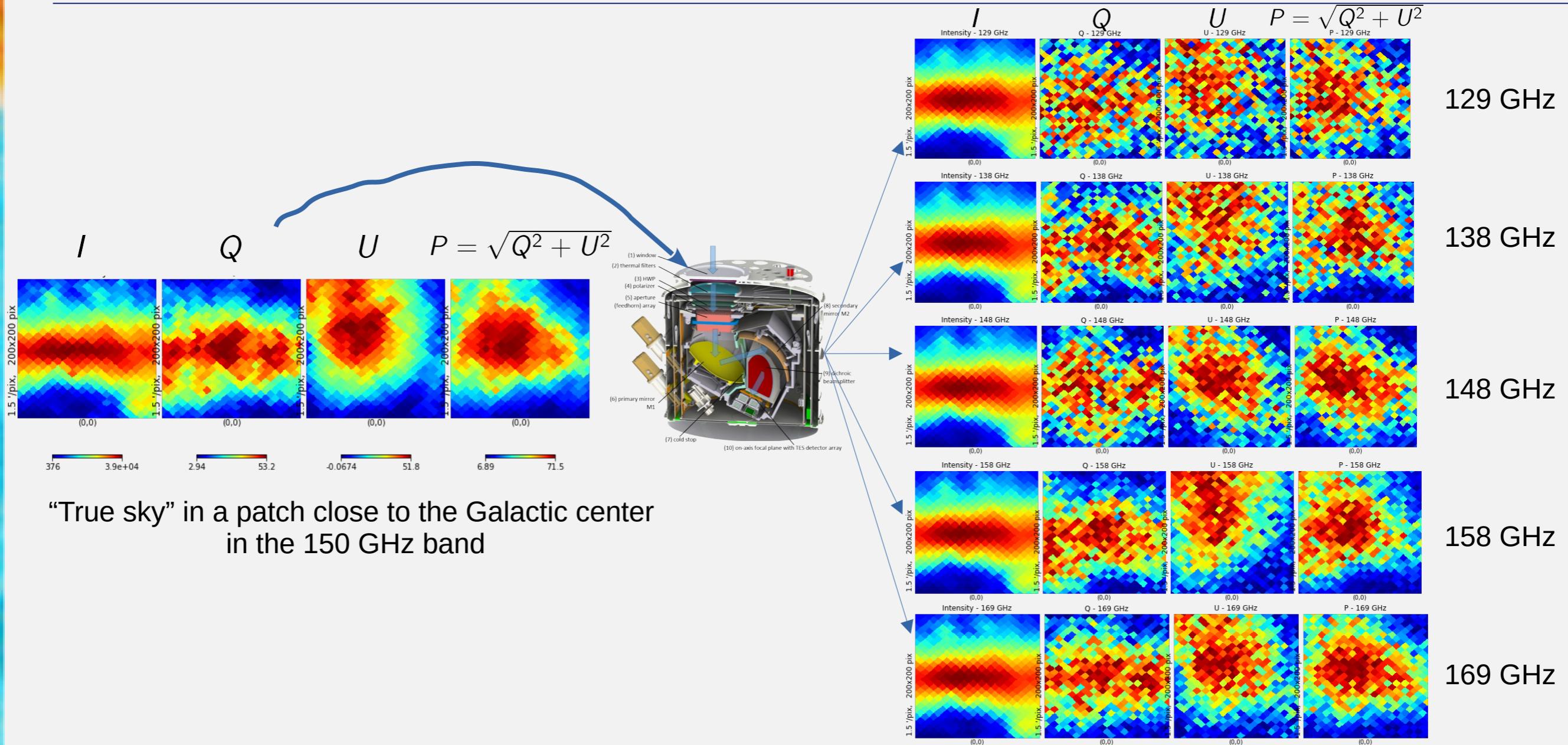


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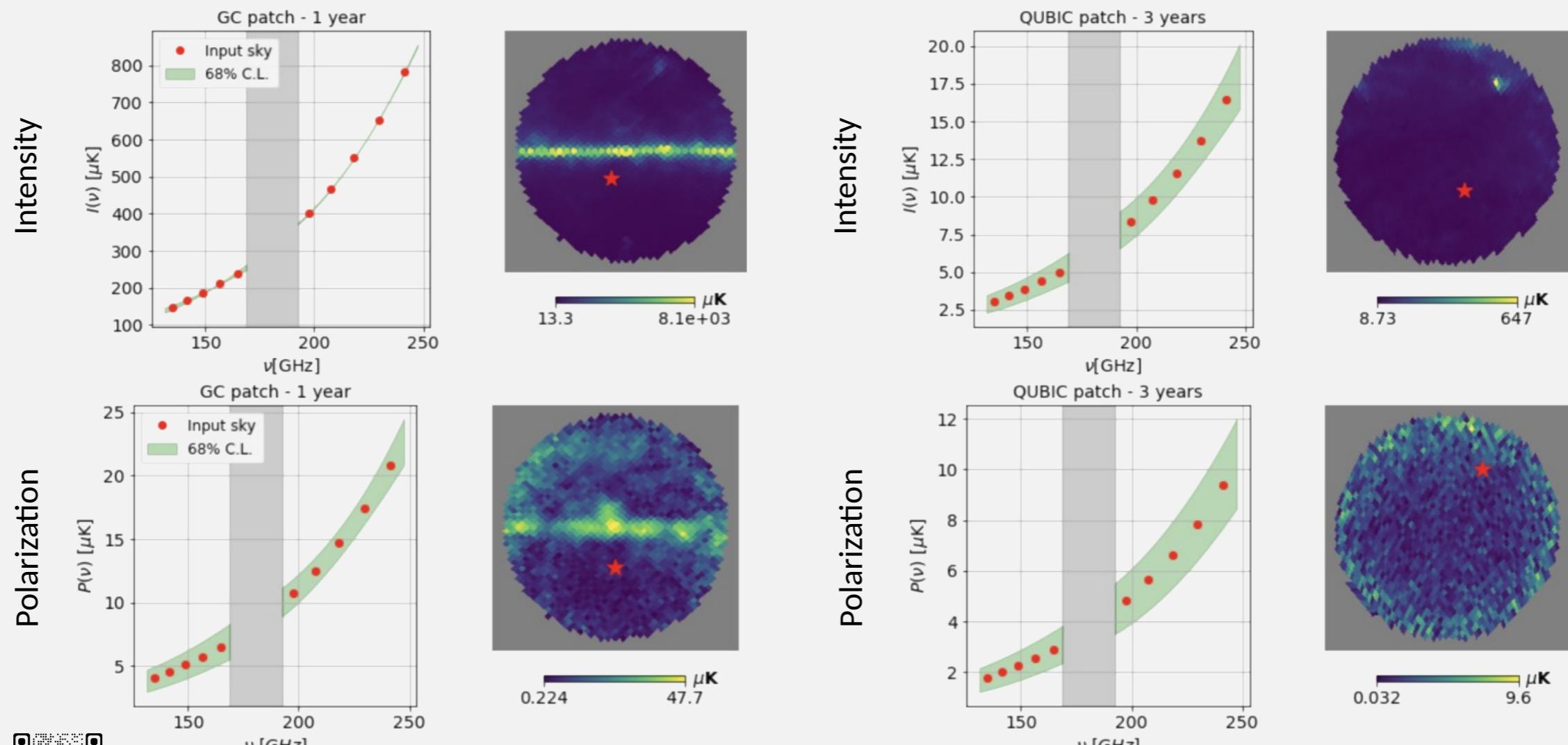


“True sky” in a patch close to the Galactic center  
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# QUBIC in a nutshell: spectral imaging



# QUBIC science: foregrounds



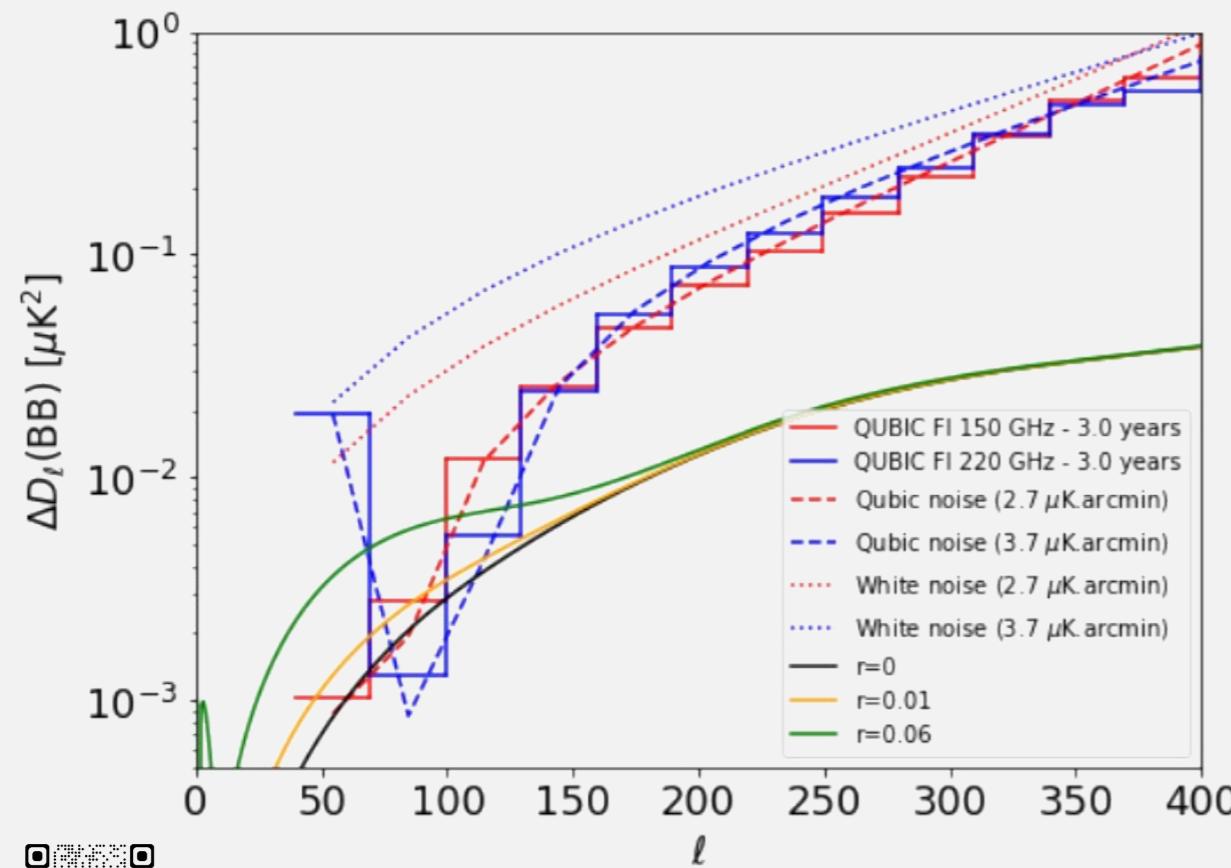
QUBIC Collaboration, 2022



# QUBIC science: tensor-to-scalar ratio

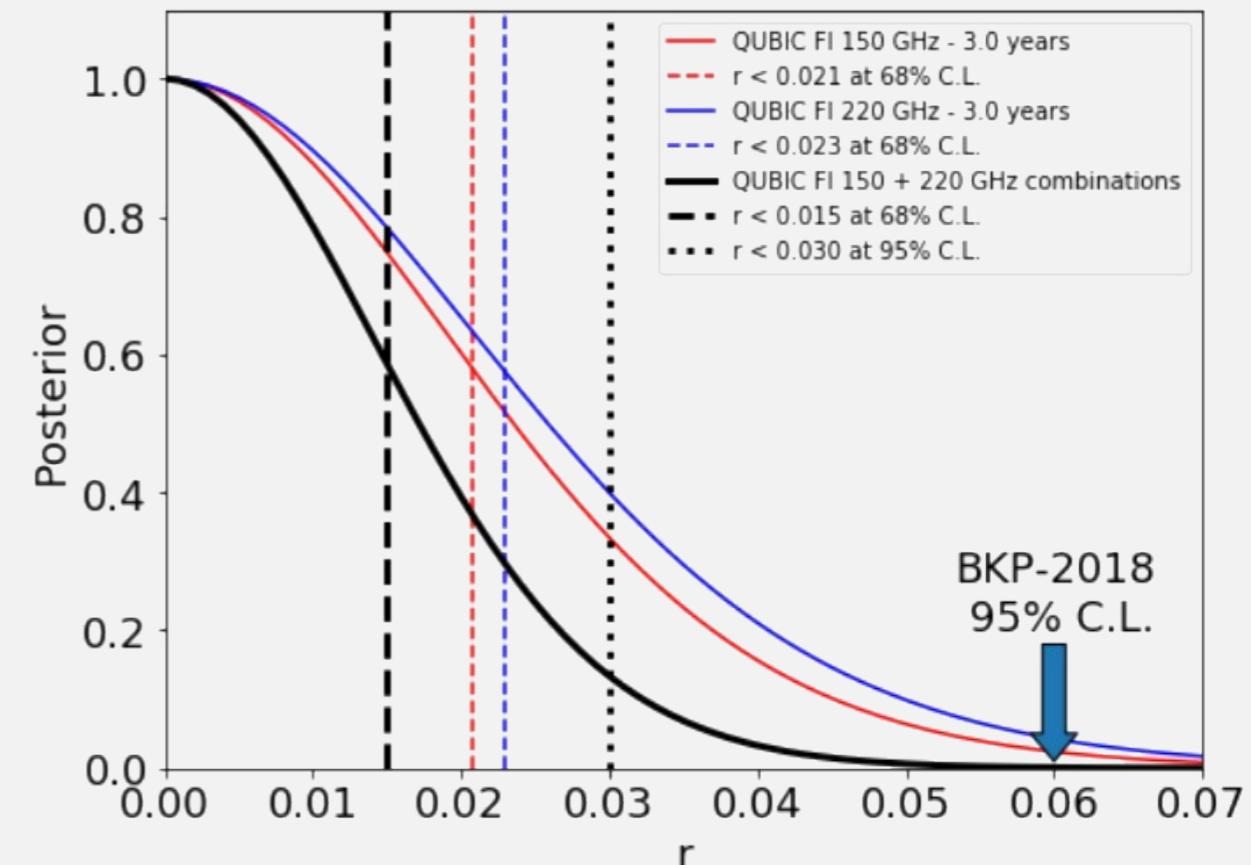
## Noise-only simulations

Error bars



QUBIC Collaboration, 2022

Posterior distribution



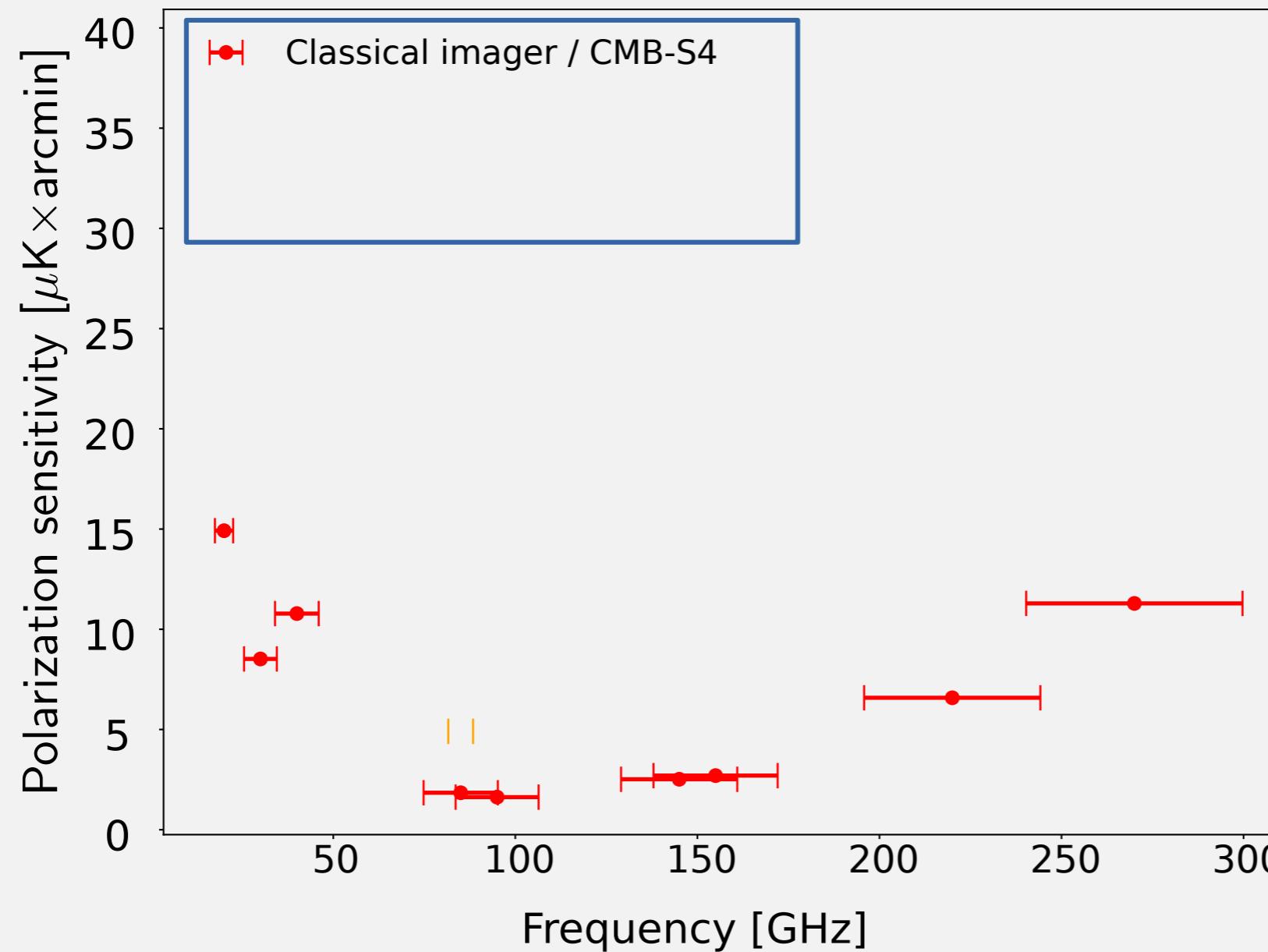
# QUBIC science: detecting foreground residuals

- Spectral imaging is powerful in detecting foreground residuals in case of complex SEDs not accounted for in component separation
- End-to-end component separation simulation (FGBuster) with dust frequency decorrelation not considered in component separation (***more in Elenia Manzan's presentation***)
- Two instrument models:
  - ▶ *Imager with CMB-S4 performance*
  - ▶ *Bolometric interferometer with comparable noise performance (CMB-S4/BI)*
- ***Spoiler: a traditional imager yields a biased detection of the tensor-to-scalar ratio, a bolometric interferometer detects the systematic effect***



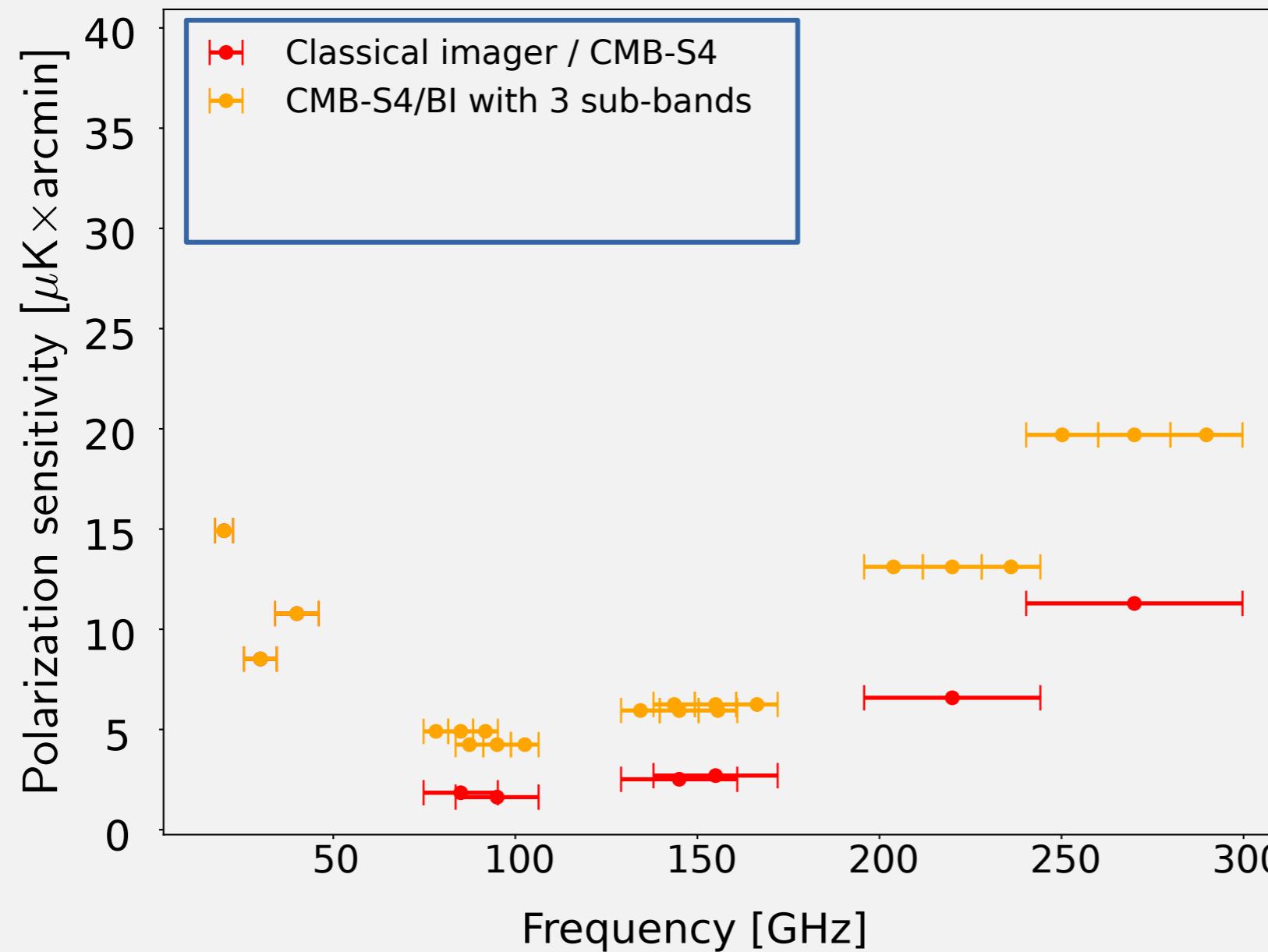
# QUBIC and foreground residuals: instrument models

Regnier, Manzan et al, A&A, to be submitted



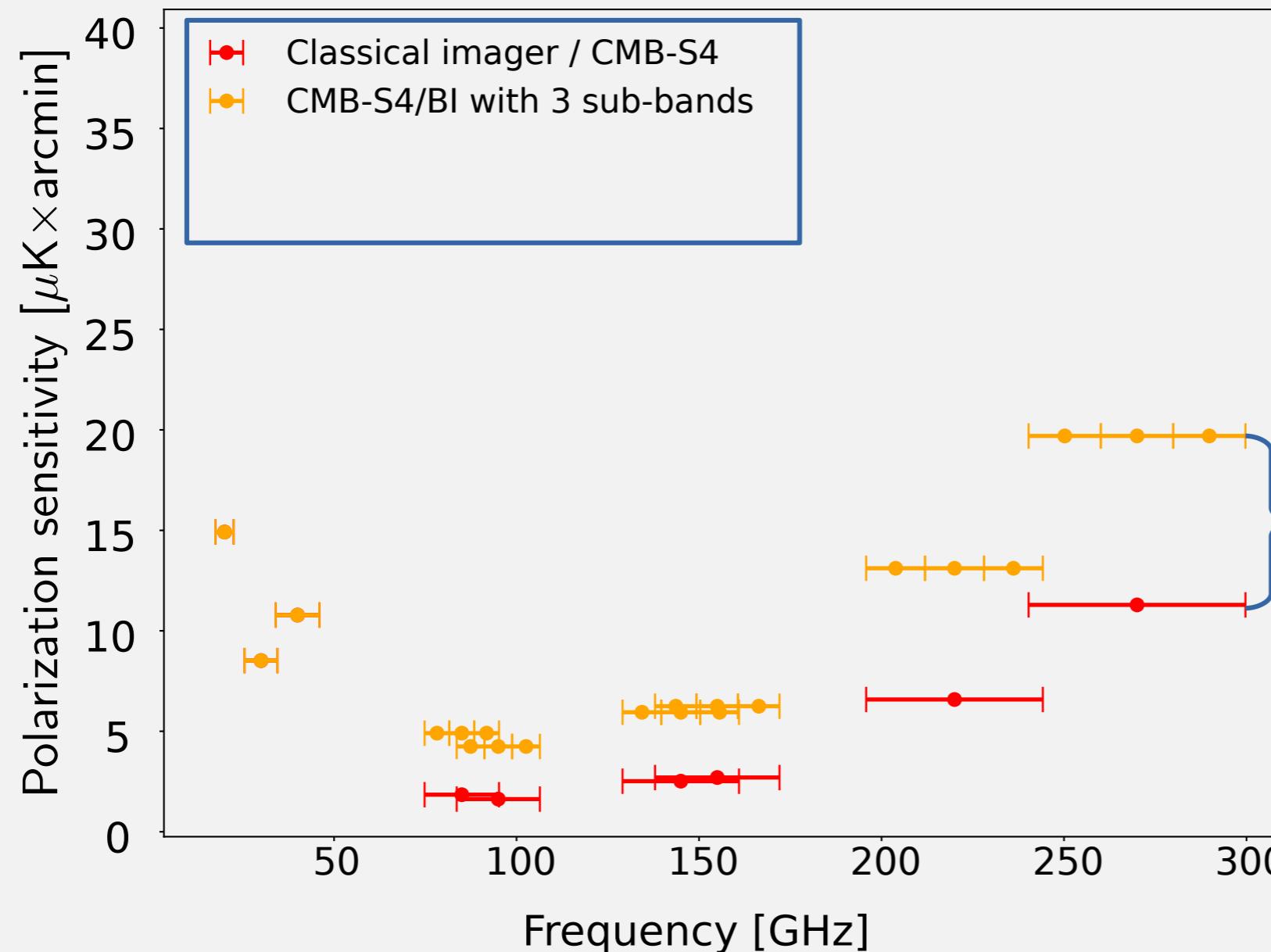
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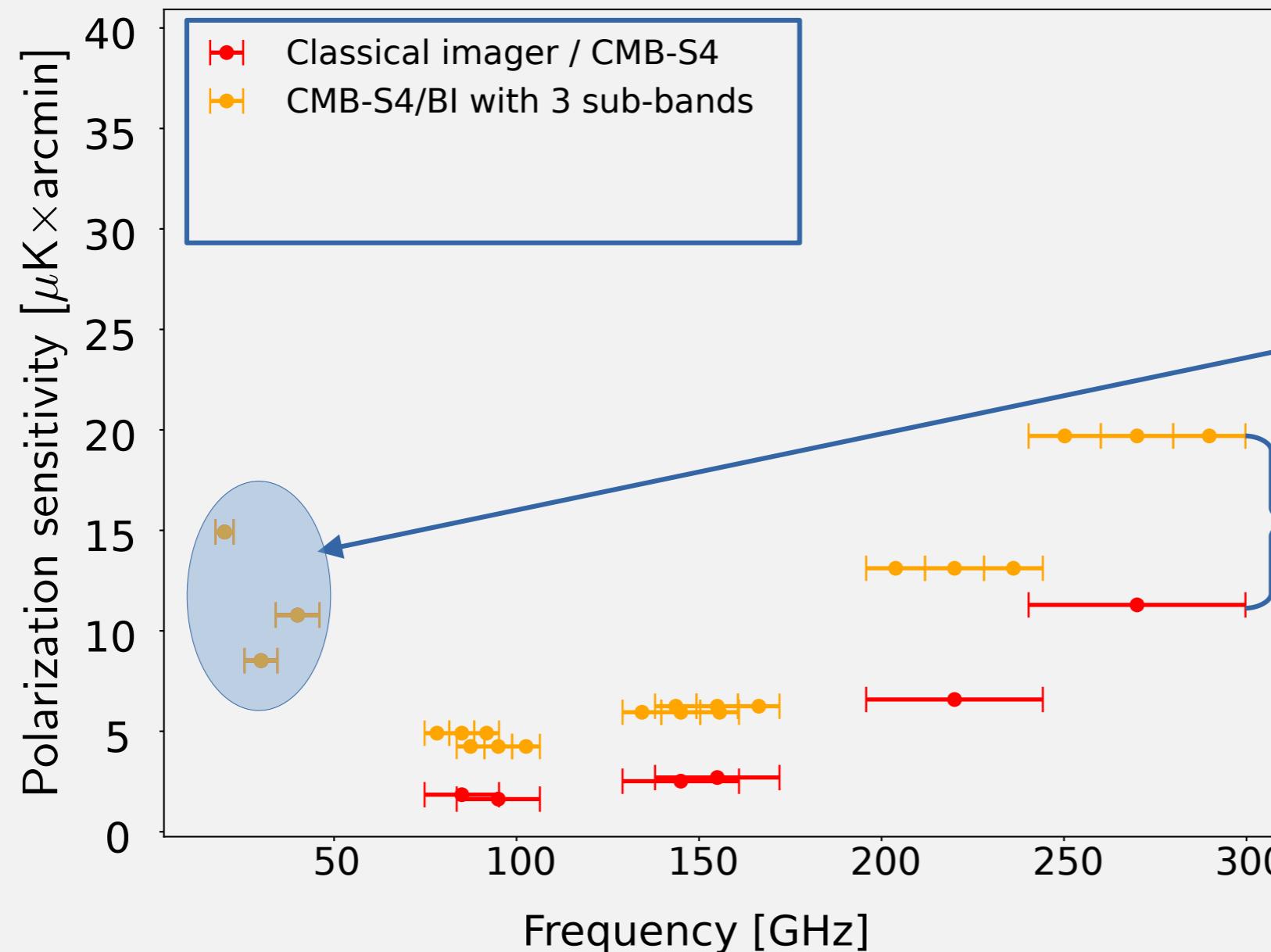


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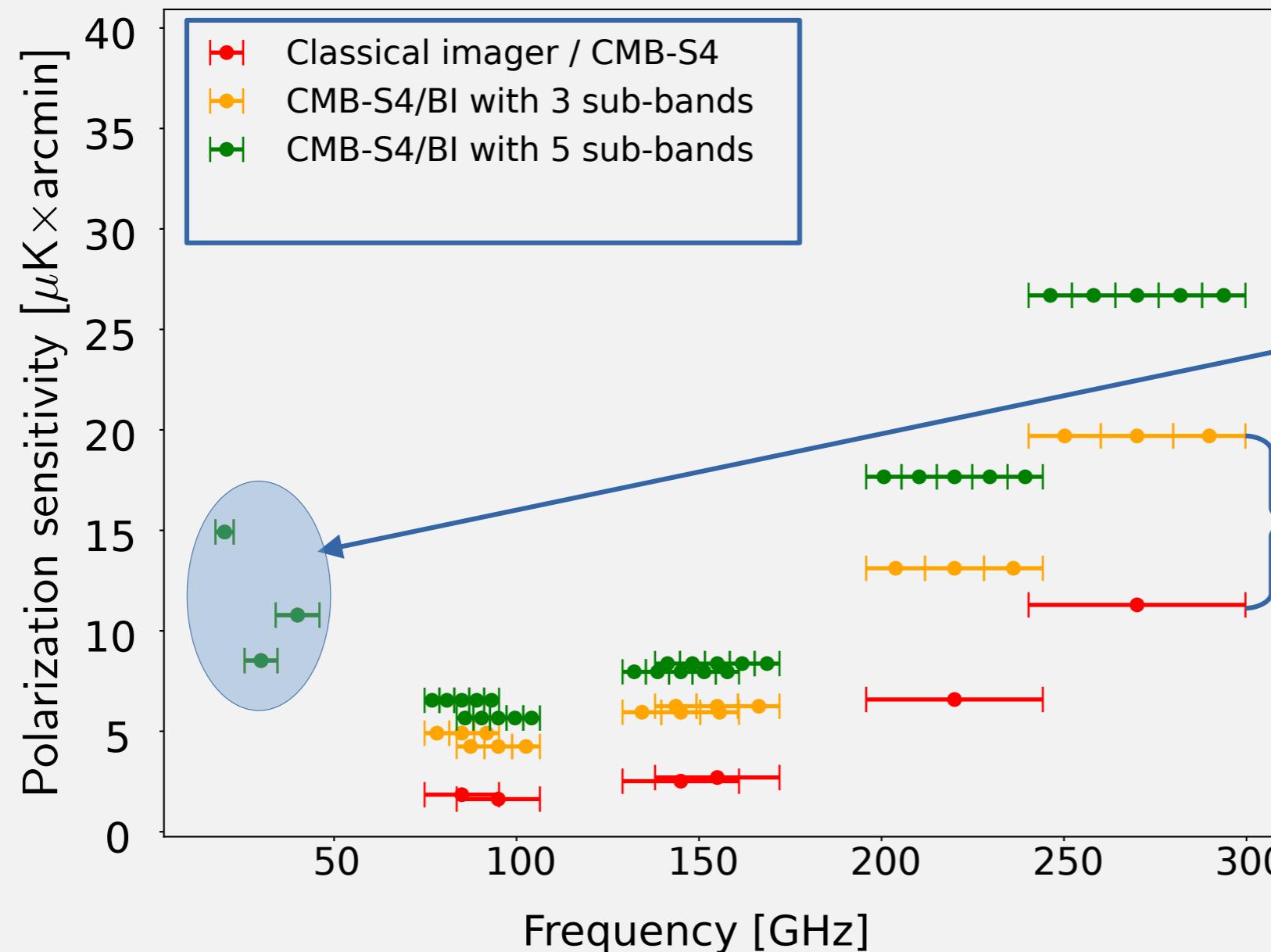
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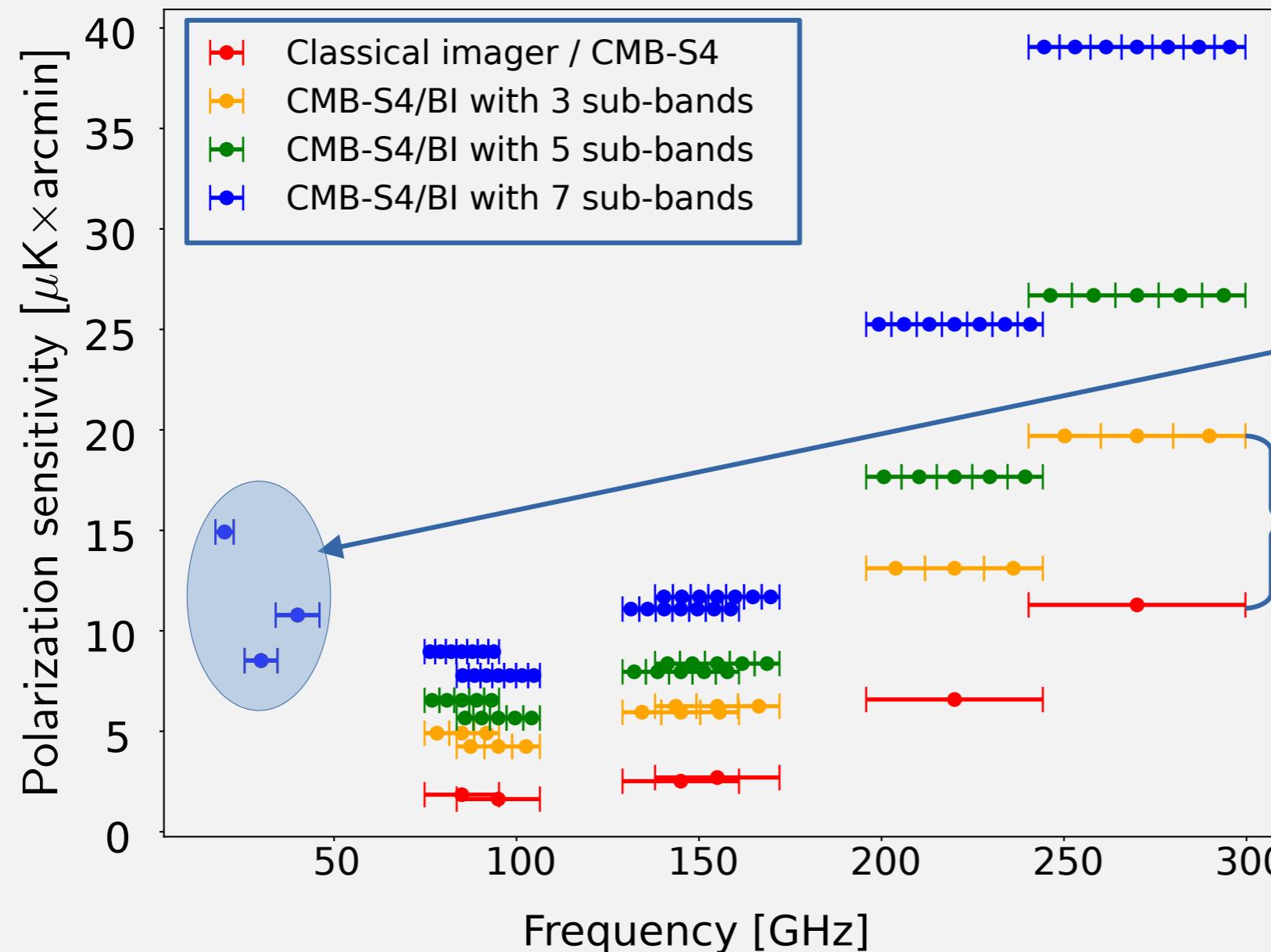
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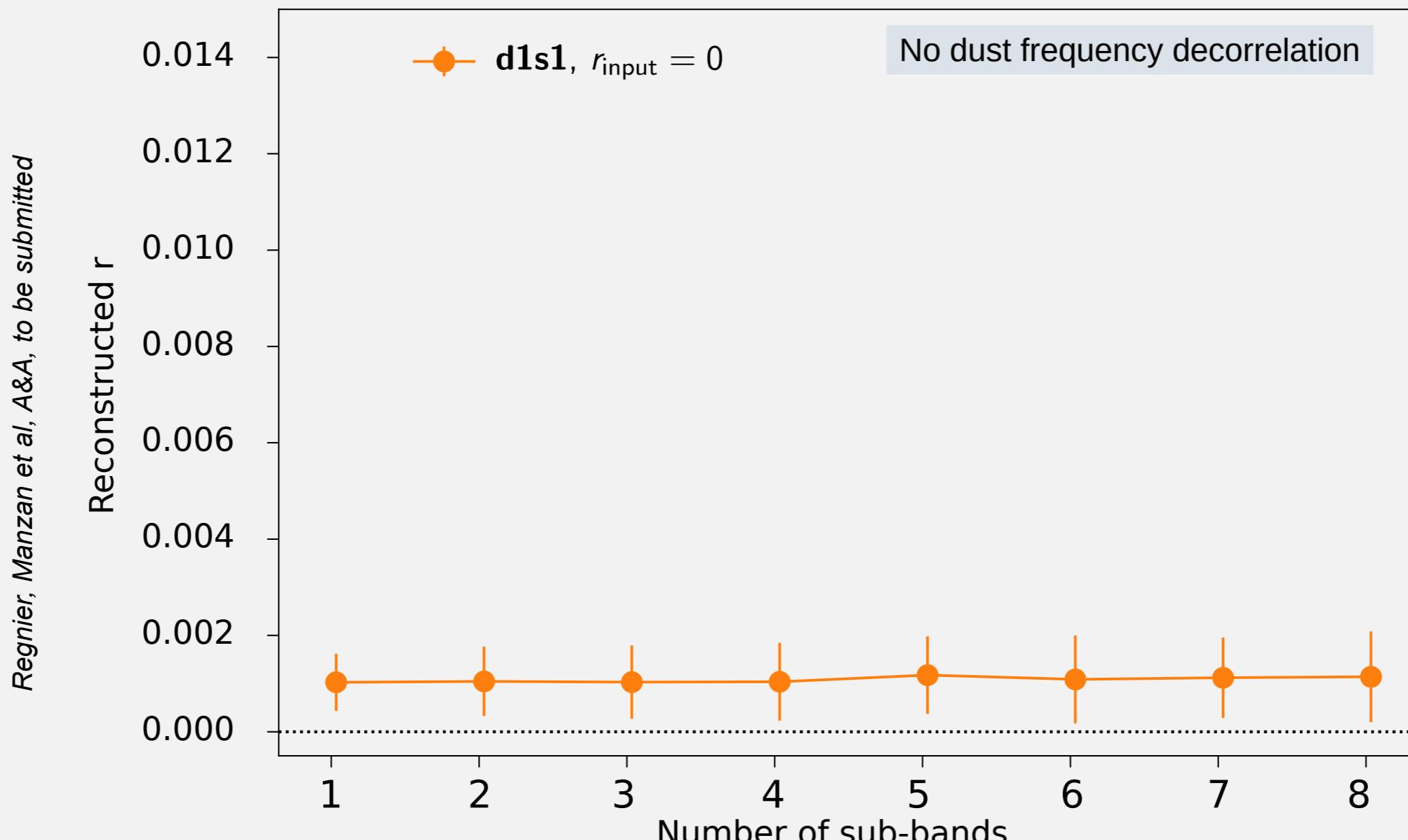
Regnier, Manzan et al, A&A, to be submitted

Exercise focusing on dust foregrounds, so low frequency bands of CMB-S4/BI coincide with those of CMB-S4

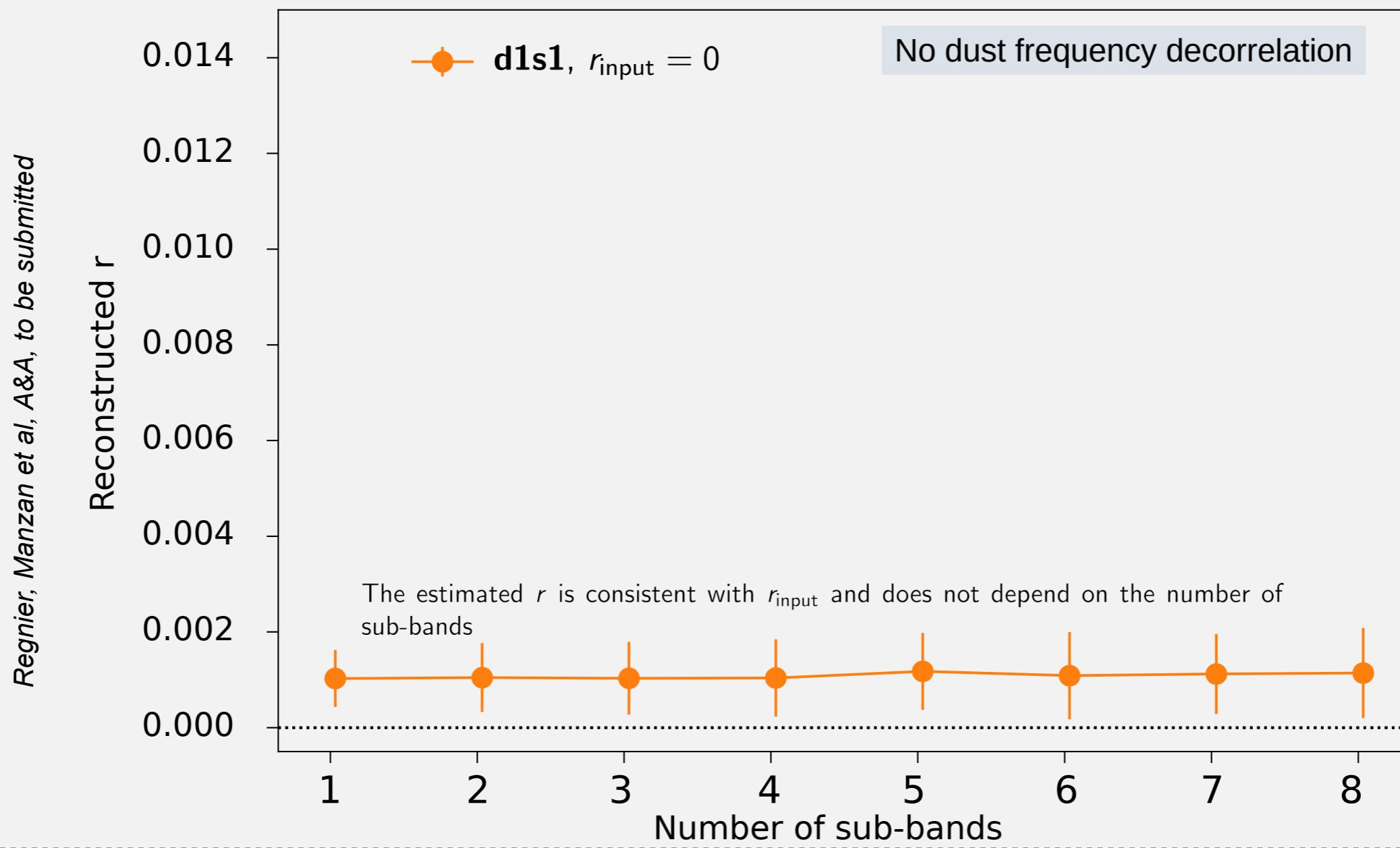
Noise increase per band due to smaller bandwidth



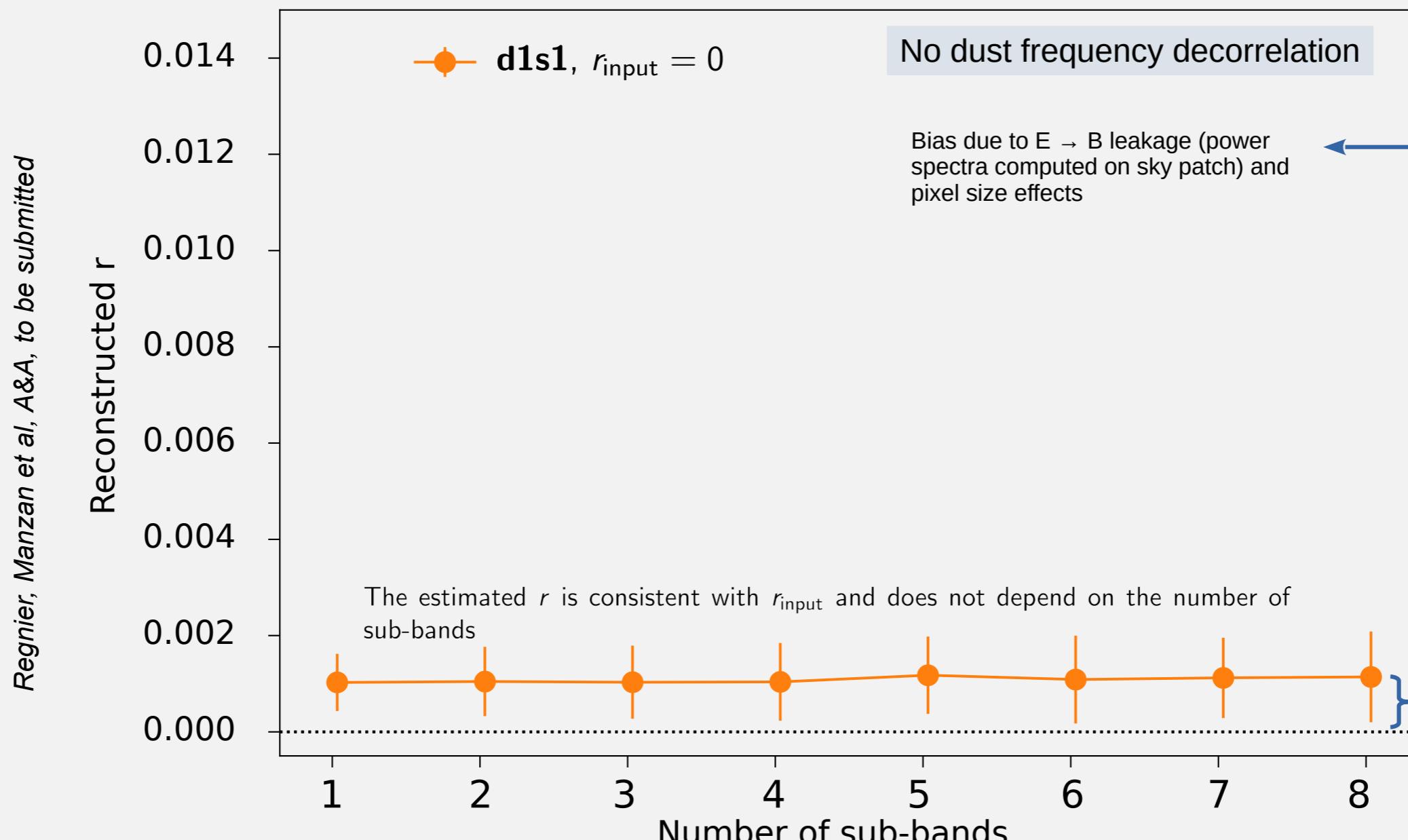
# QUBIC and foreground residuals: results highlight



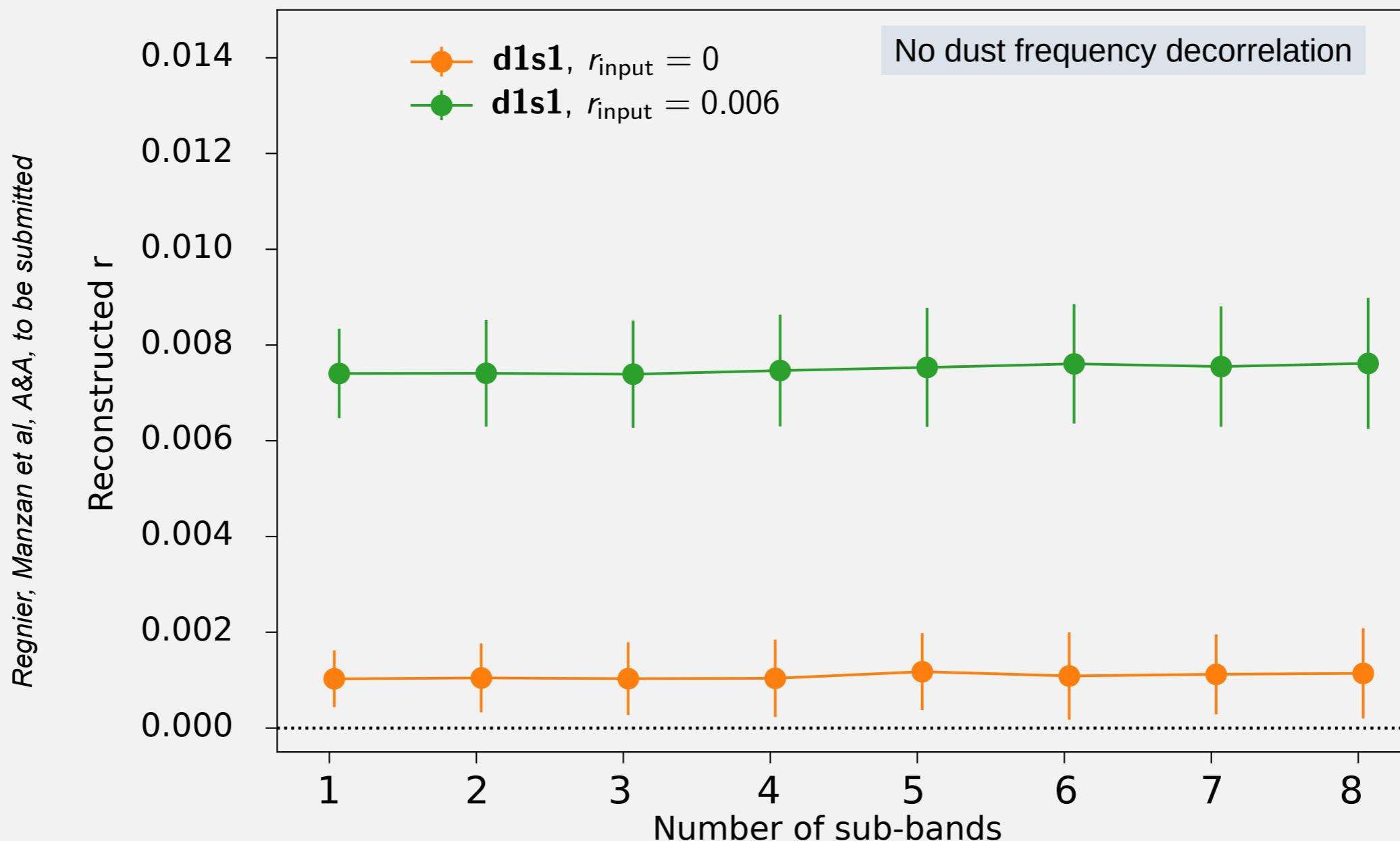
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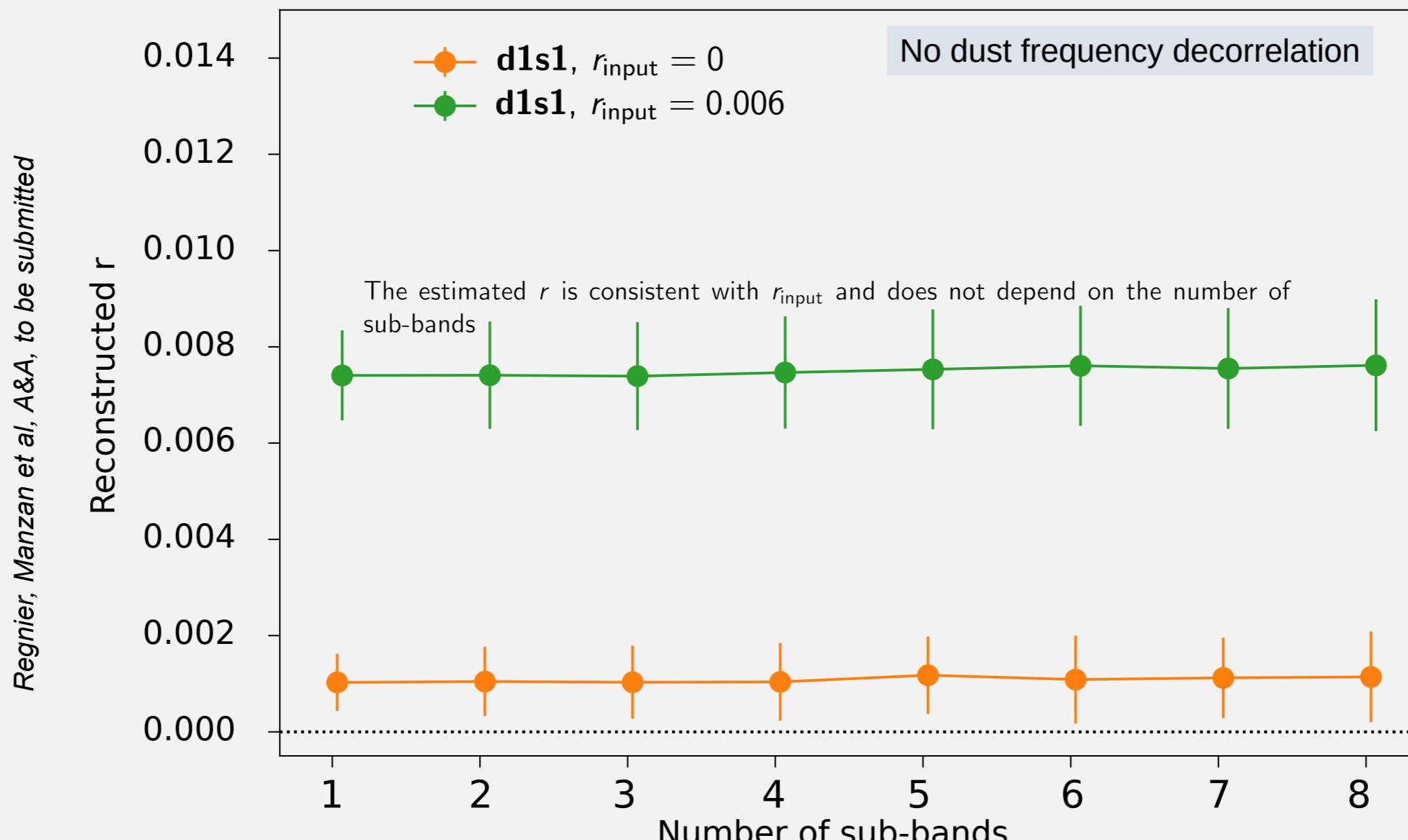
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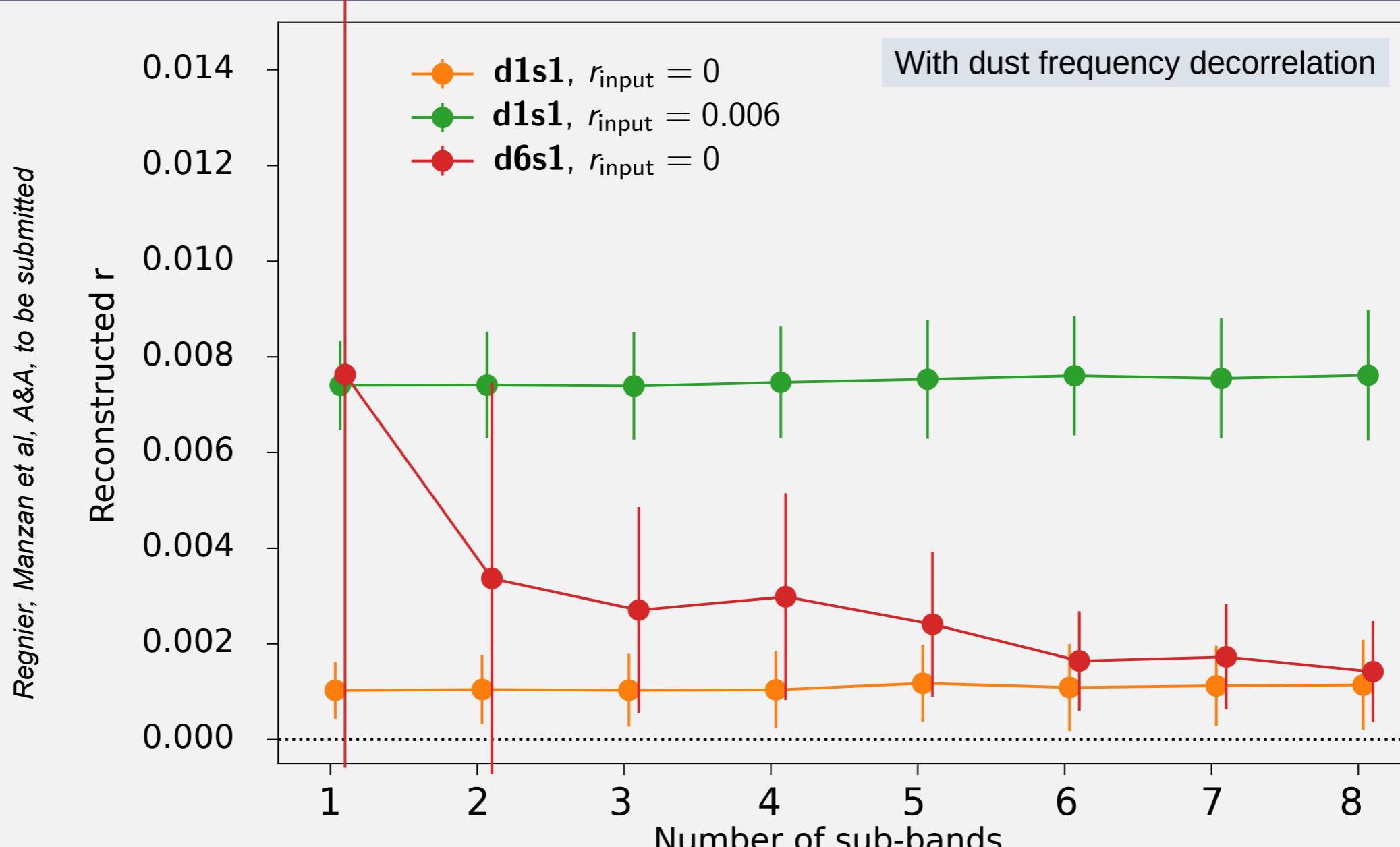
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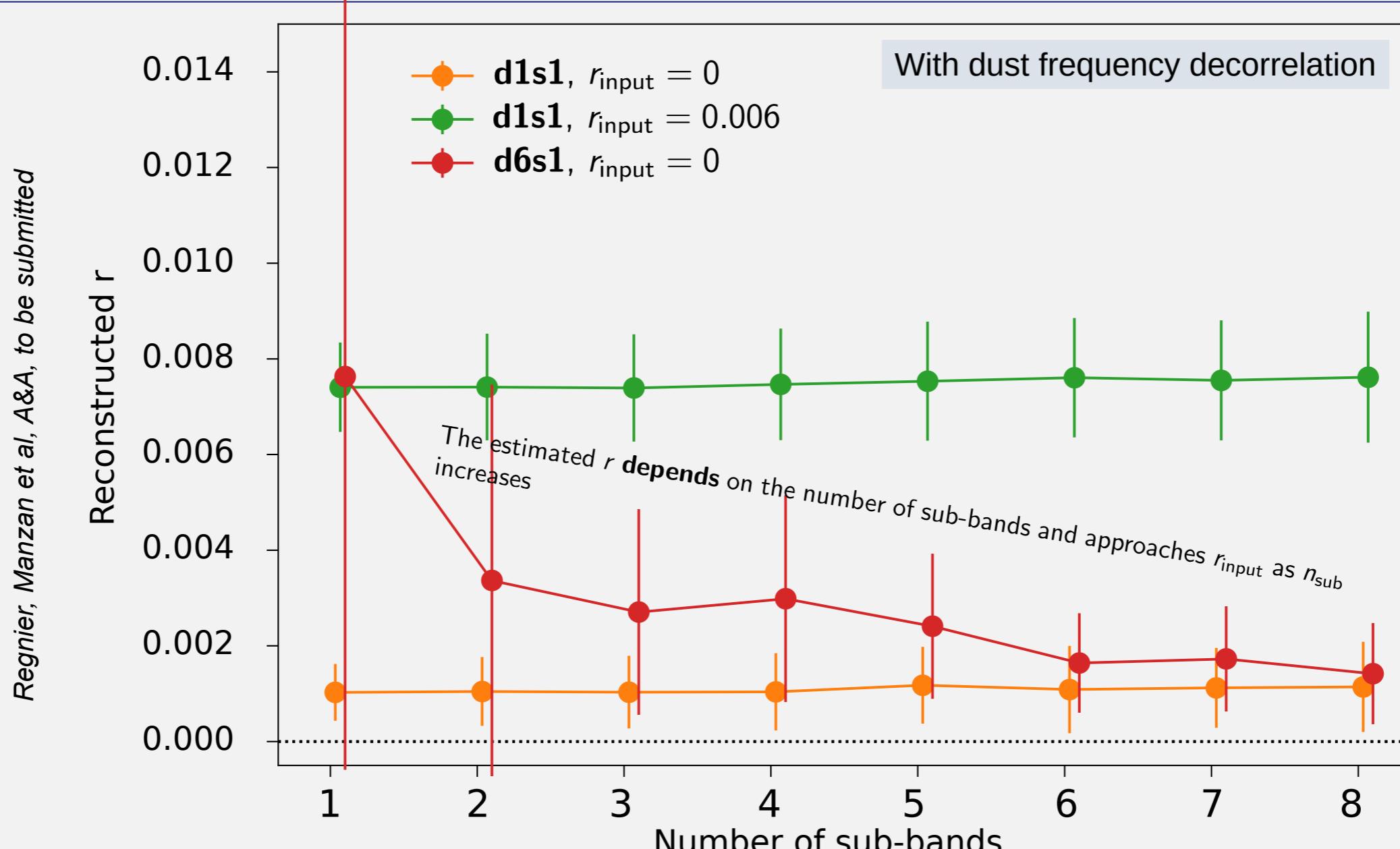
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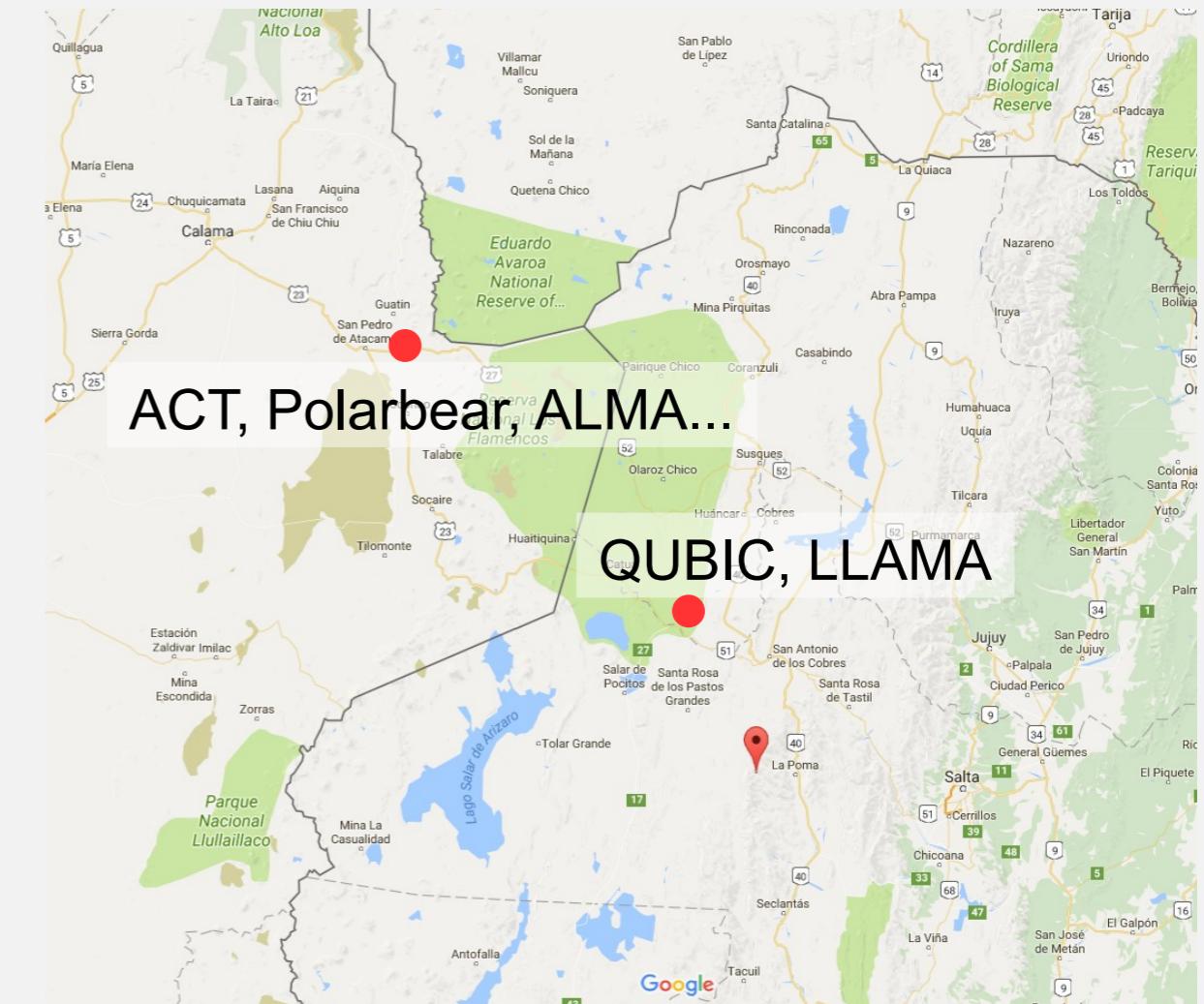


# QUBIC and foreground residuals: results highlight



# QUBIC: observation site

Alto Corillo, Salta province (Argentina), 5000 a.s.l., near San Antonio de Los Cobres



# QUBIC: status and perspectives



Aniello Mennella

Measuring the CMB primordial B-modes with Bolometric Interferometry

LPSC – Grenoble, 29 June 2023

## ■ QUBIC-TD

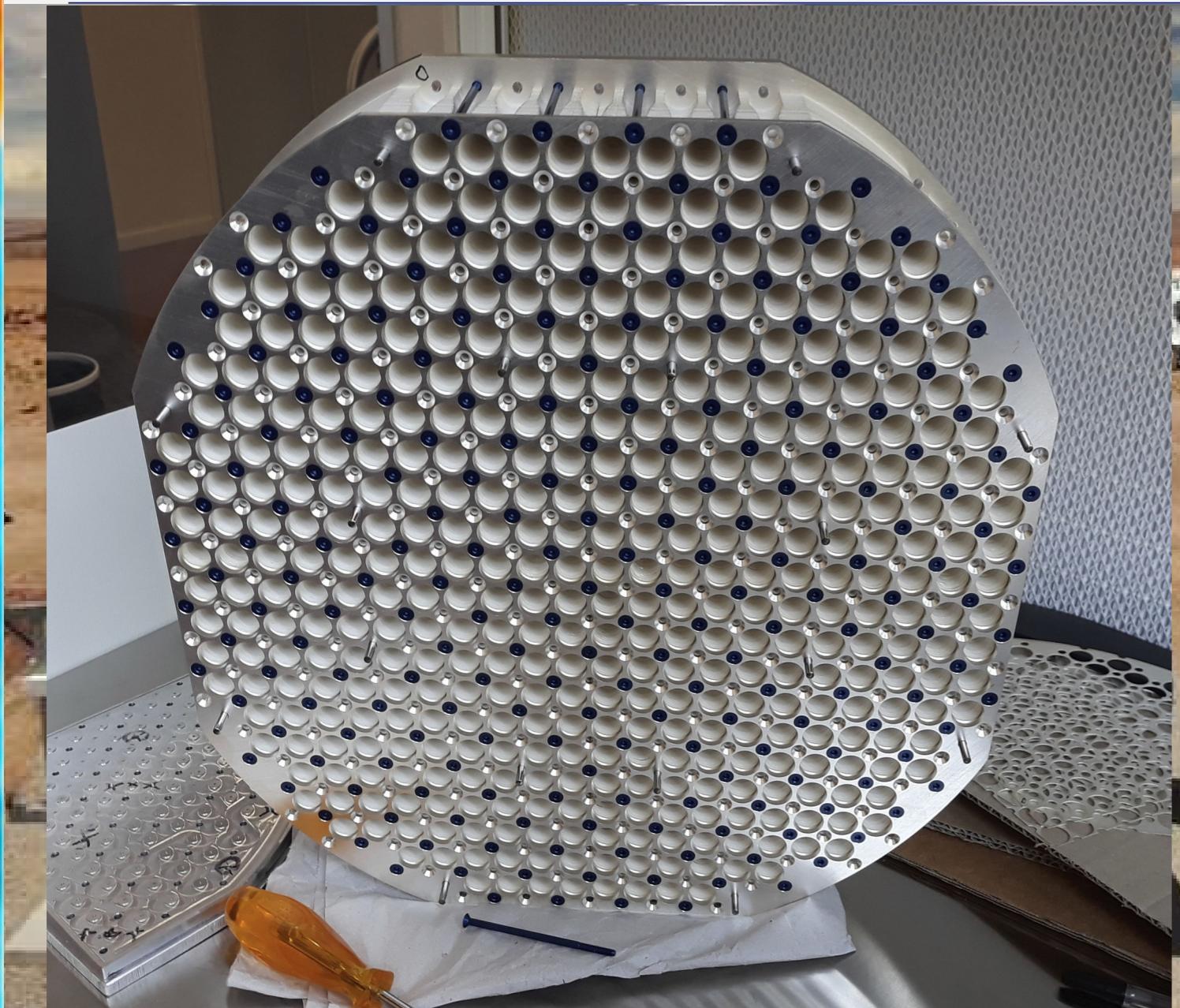
- Deployed during Nov. 2022
- Currently under commissioning
- Observations (atmosphere, galactic regions, Moon) scheduled for 2023/2024

## ■ QUBIC-FI

- Some parts already available (horns, mirrors), some under final development (detectors, switches, dichroic)
- Cryostat, forebaffle are the same
- Deployment foreseen for late 2024



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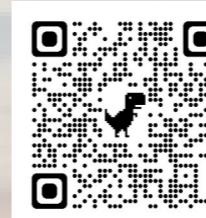
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# QUBIC – JCAP paper series



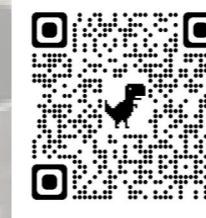
**QUBIC I: Overview and science program**



**QUBIC V: Cryogenic system design and performance**



**QUBIC II: Spectral polarimetry with bolometric interferometry**



**QUBIC VI: Cryogenic half wave plate rotator, design and performance**



**QUBIC III: Laboratory characterization**



**QUBIC VII: The feedhorn-switch system of the technological demonstrator**



**QUBIC IV: Performance of TES bolometers and readout electronics**



**QUBIC VIII: Optical design and performance**



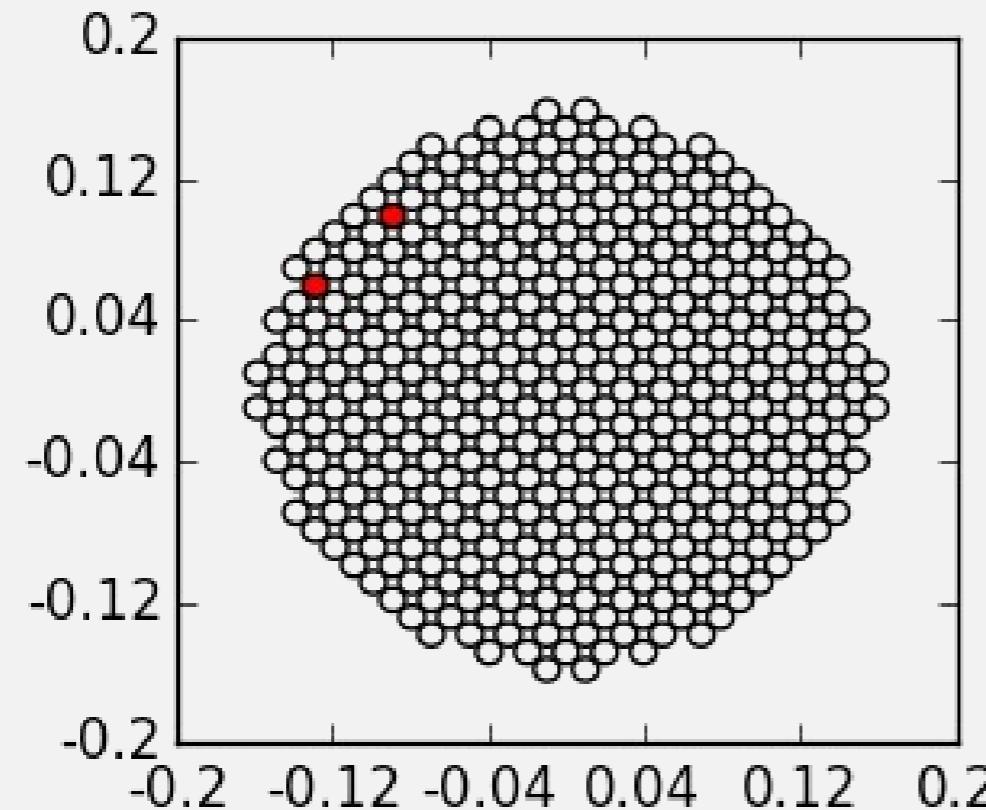
# Backup slides

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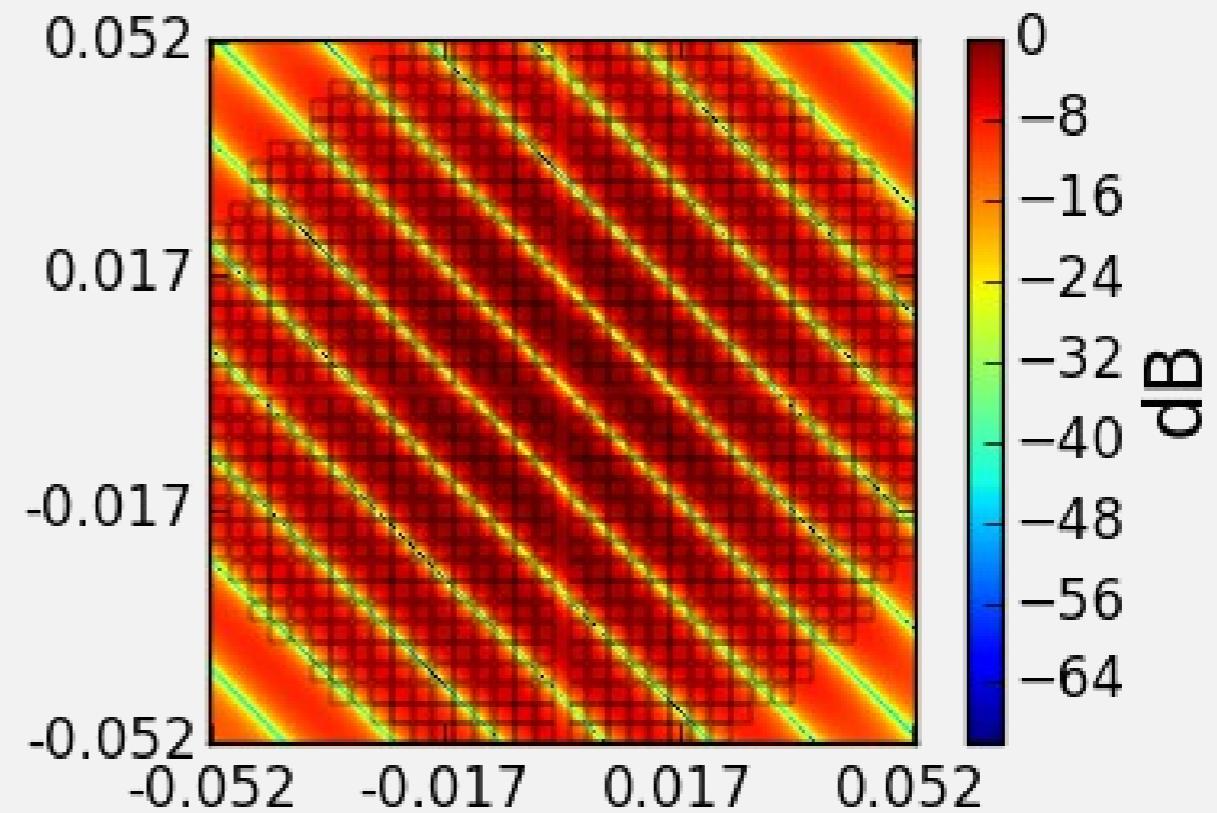
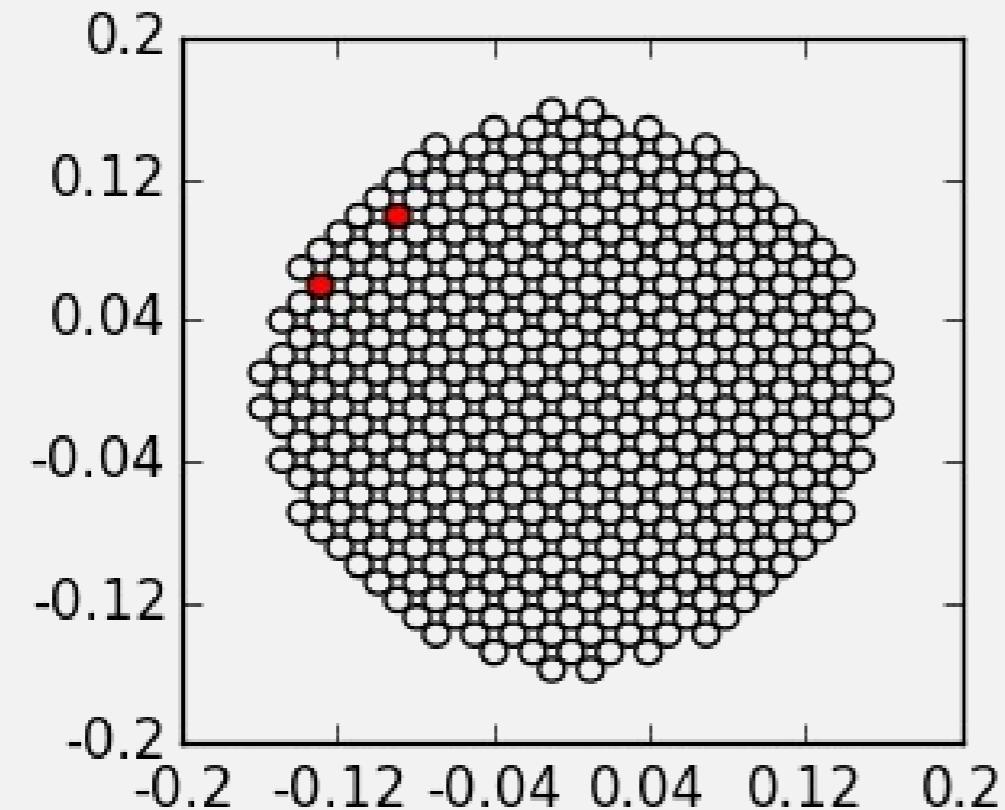
# QUBIC in a nutshell: the measurement

Response to a point source in the far field



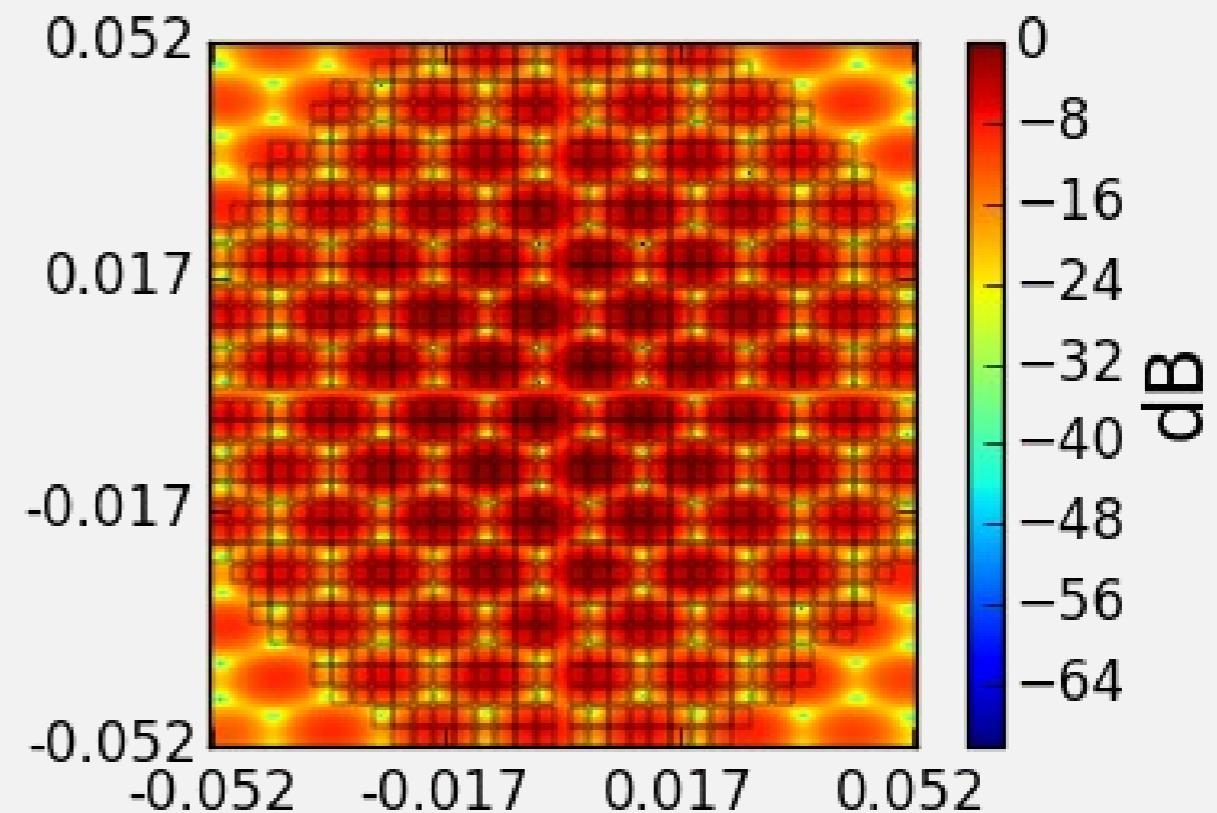
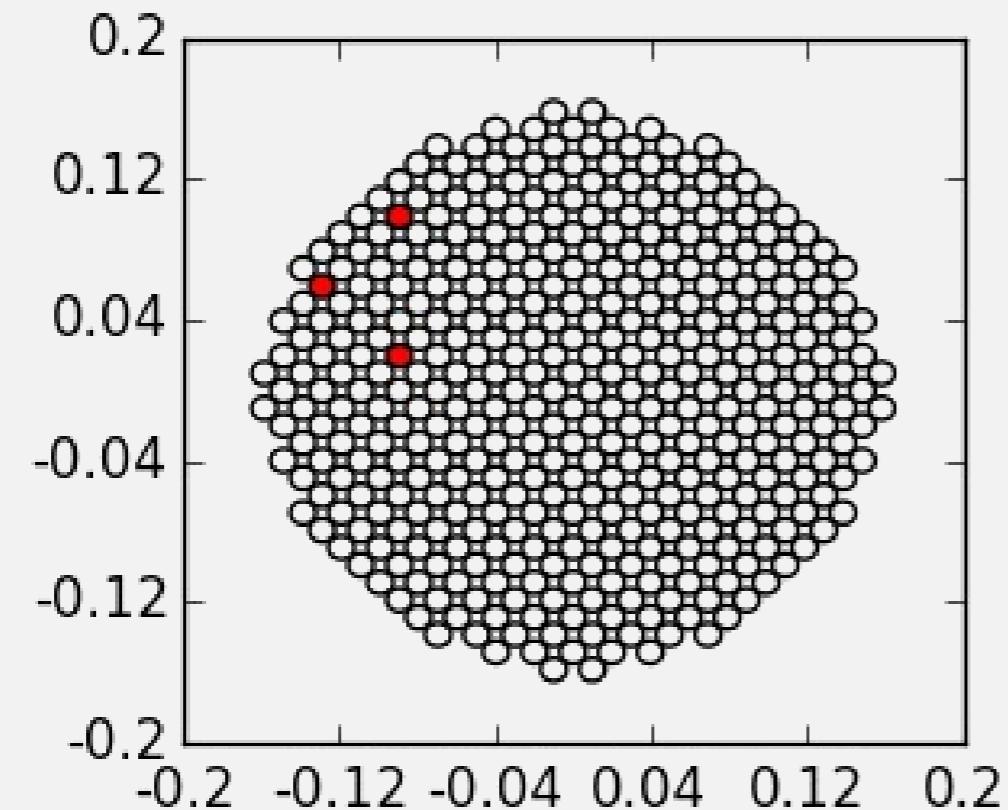
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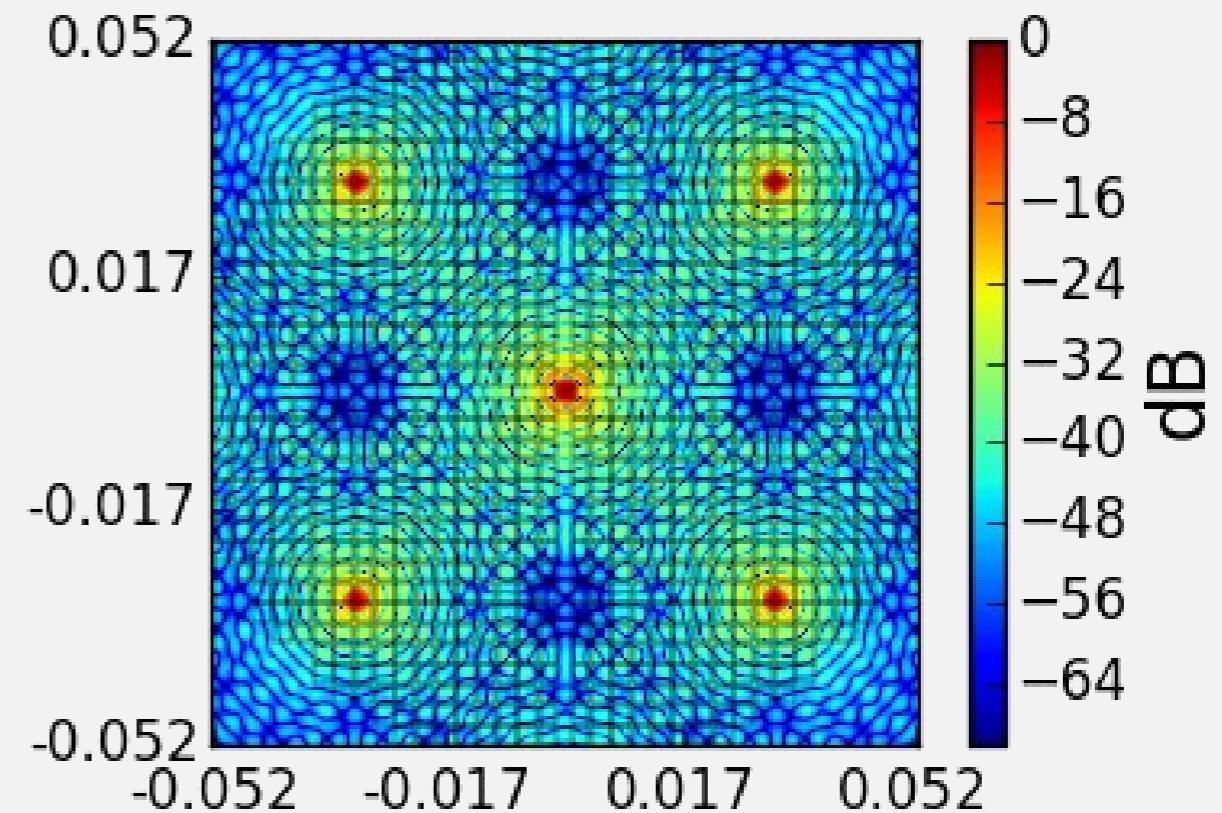
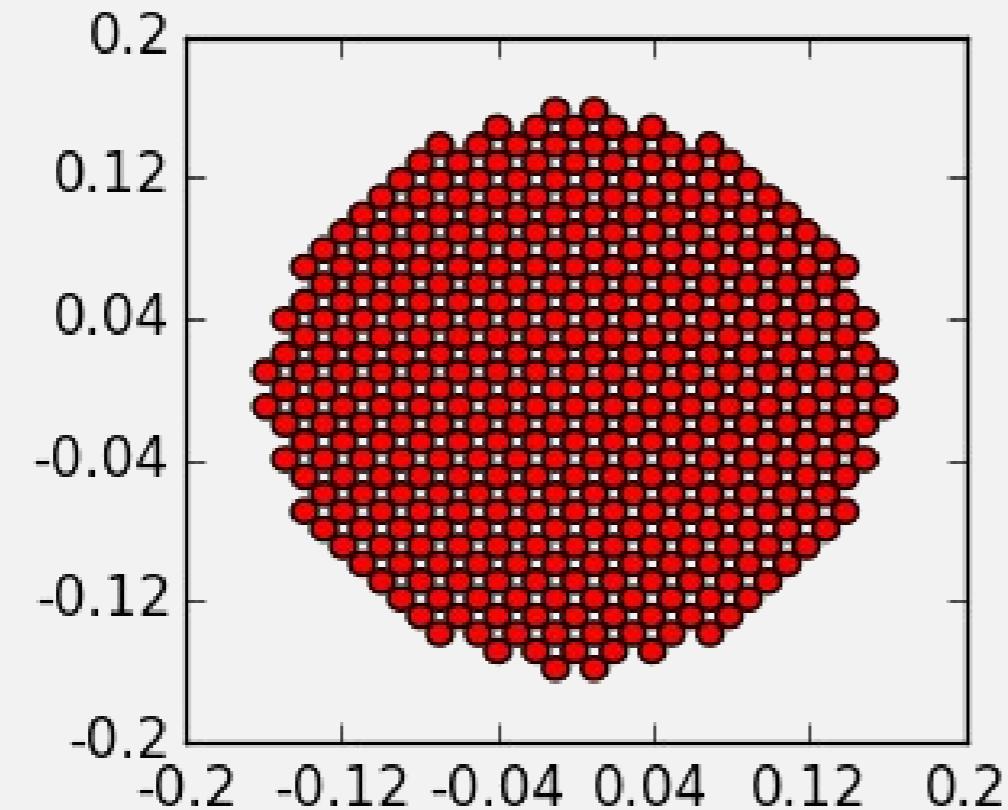
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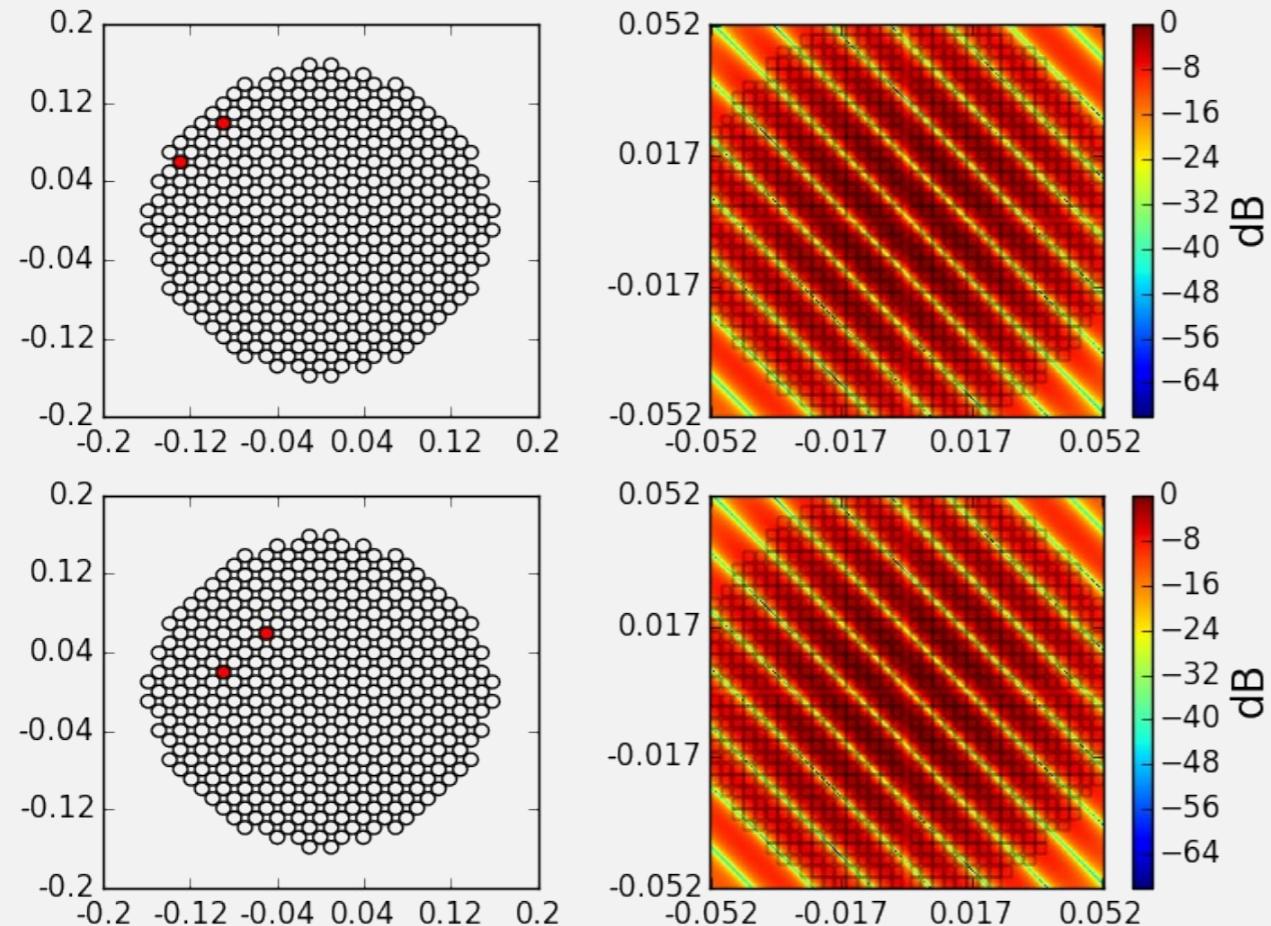
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# Self-calibration

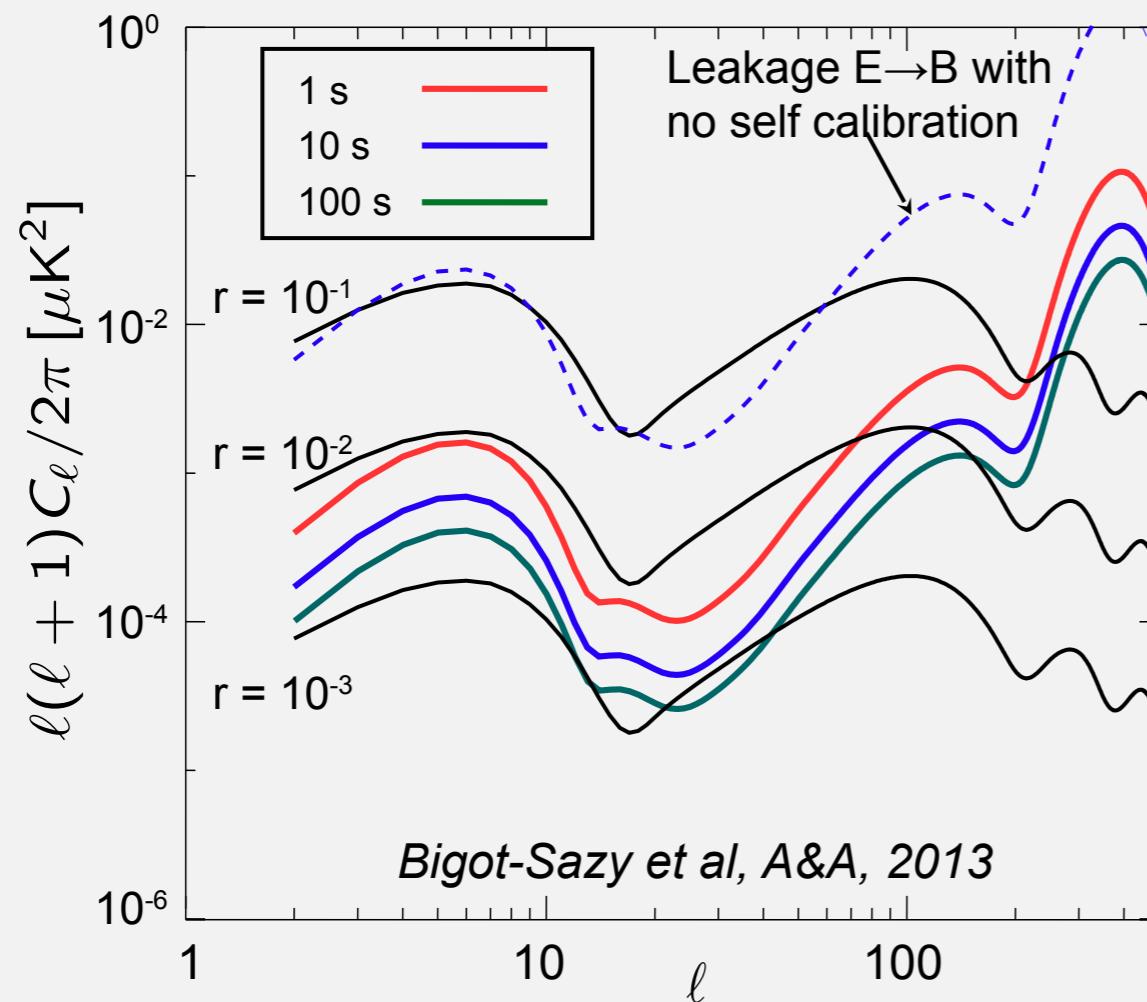
The response from equal baselines is  
in principle the same



## Self calibration mode:

- Observe an artificial source
- Acquire data with several baselines combinations
- Find instrumental parameters that minimize measurement differences for each baseline

# Self-calibration



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