

QUBIC: Exploring the primordial Universe with the Q&U Bolometric Interferometer

Aniello Mennella for the QUBIC collaboration

University of Milan, Dept. of Physics

INFN-Milan



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Collaboration and funding agencies

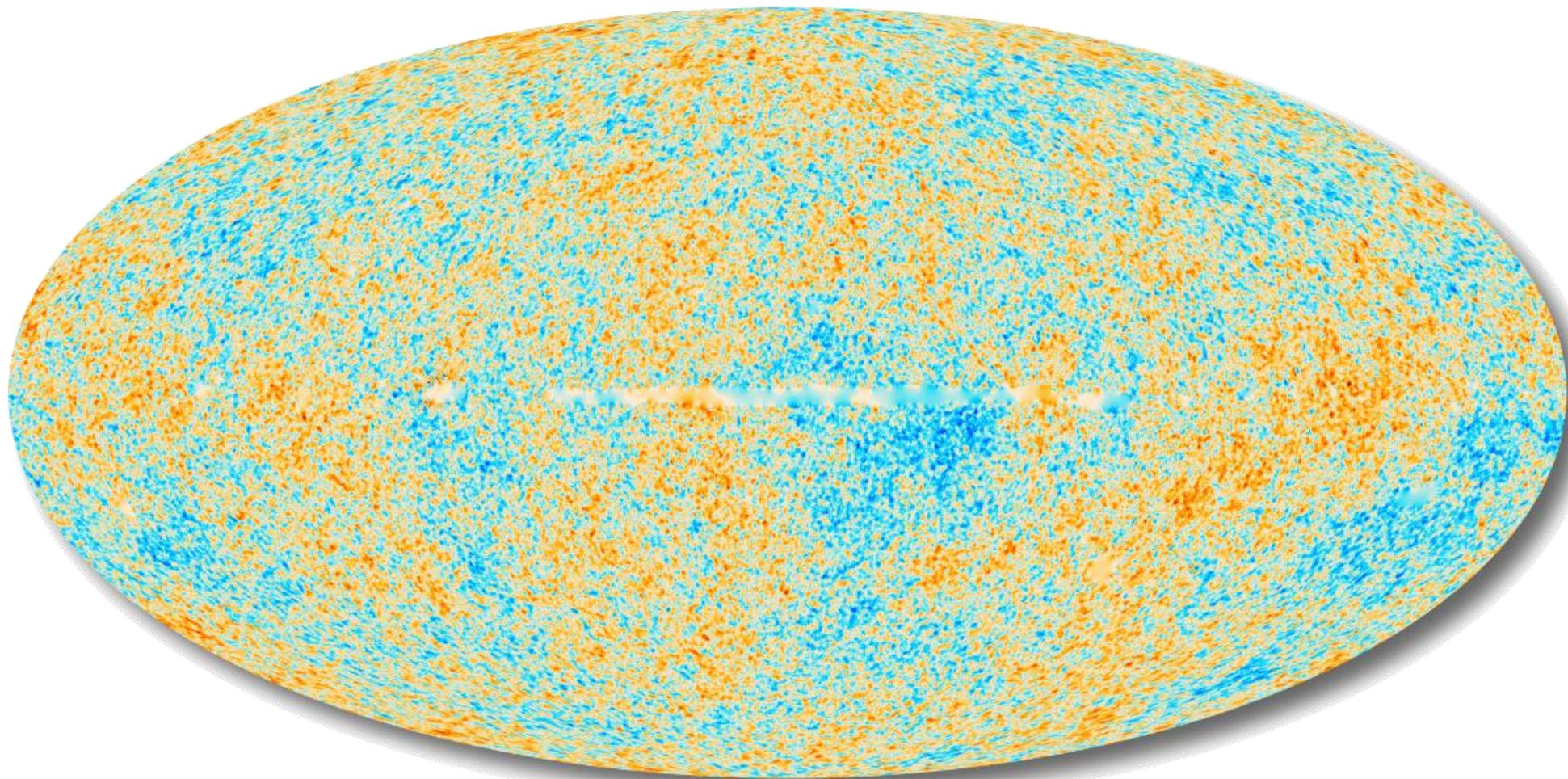
APC Paris, France
 CSNSM, France
 IAS Orsay, France
 IEF Orsay, France
 IRAP Toulouse, France
 LAL Orsay, France
 Università di Milano Bicocca
 INFN sezione di Milano Bicocca, Italy
 Università degli Studi di Milano, Italy
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 Centro Atómico Bariloche and Istituto Balseiro, Argentina
 Instituto de Tecnologías en Detección y Astroparticulas, Argentina
 Instituto Argentino de Radioastronomía, Argentina



Funding

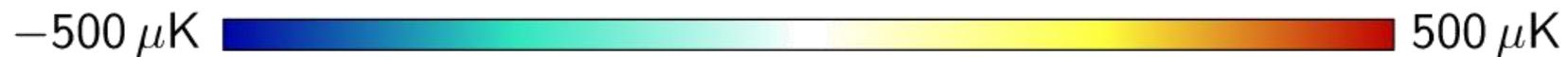


Hidden treasures

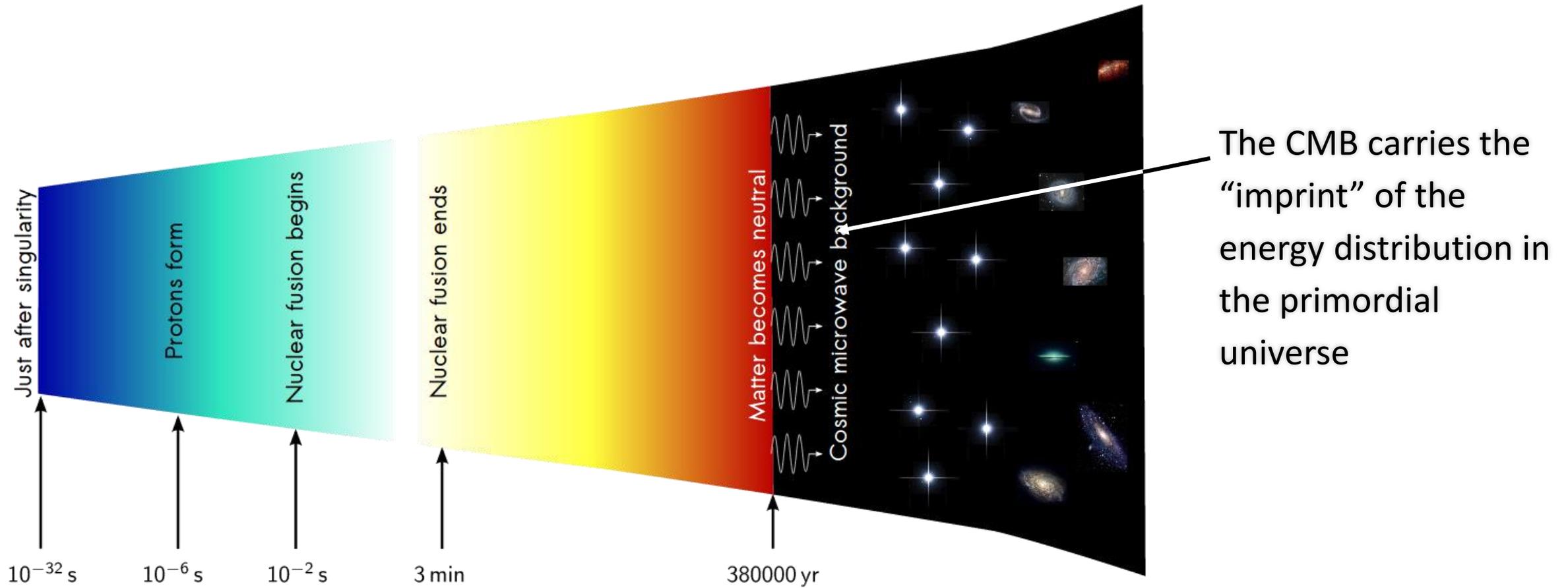


Planck

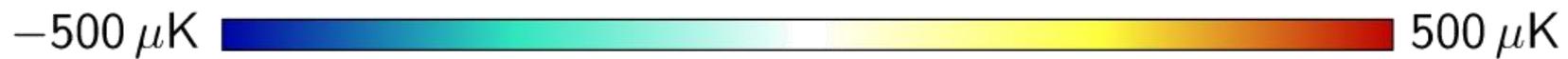
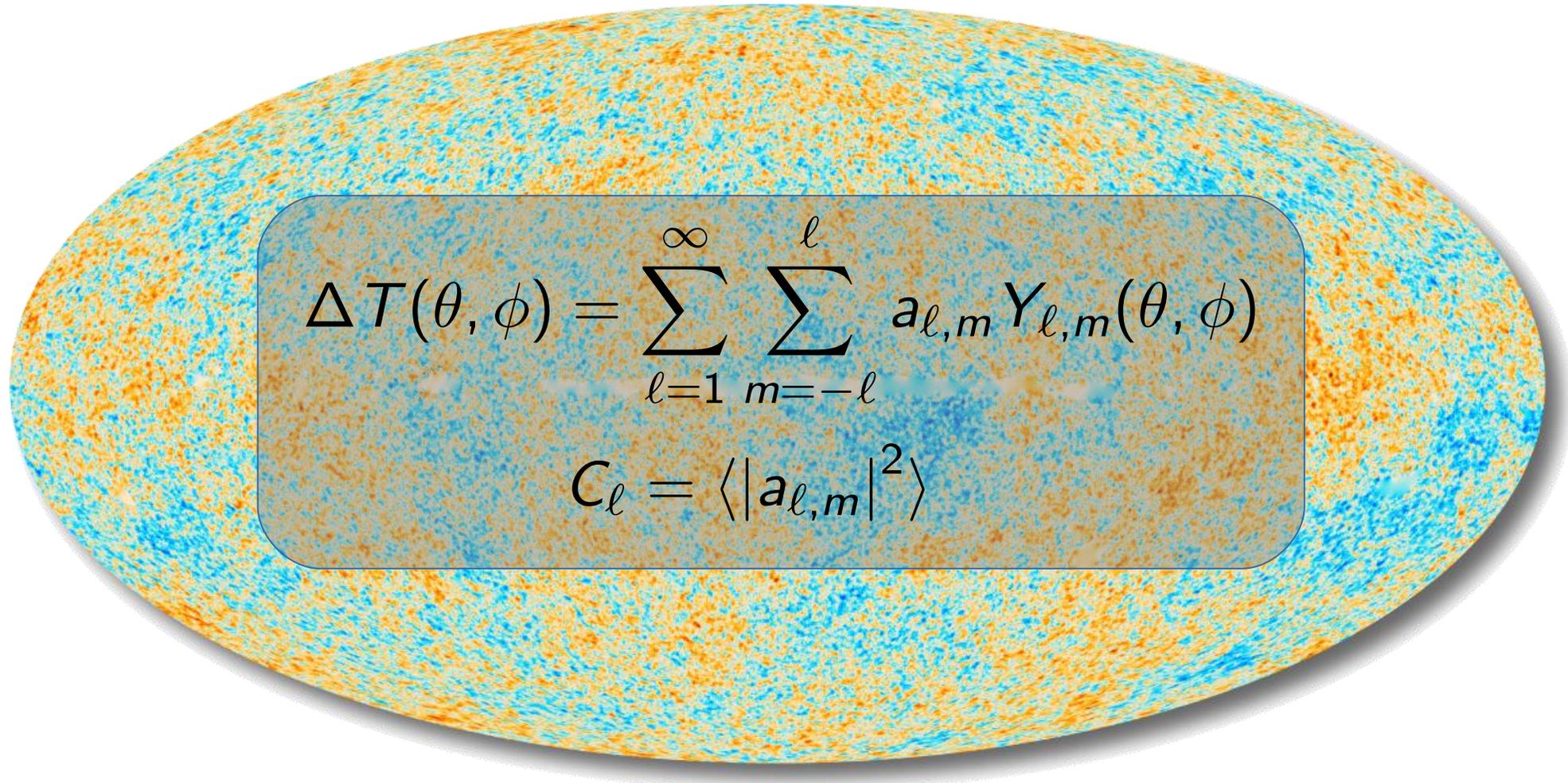
ESA mission
Launched in 2009
Operative until 2013



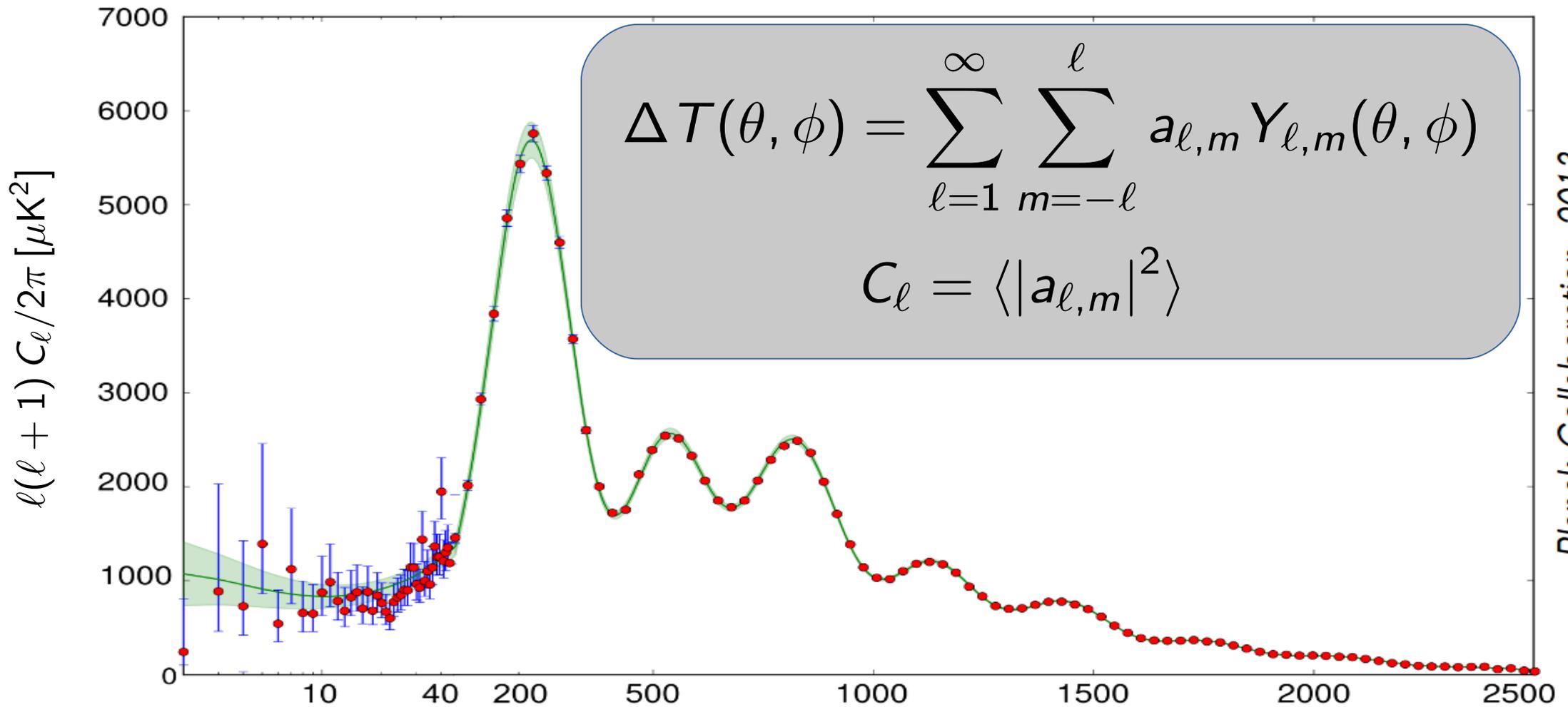
Hidden treasures



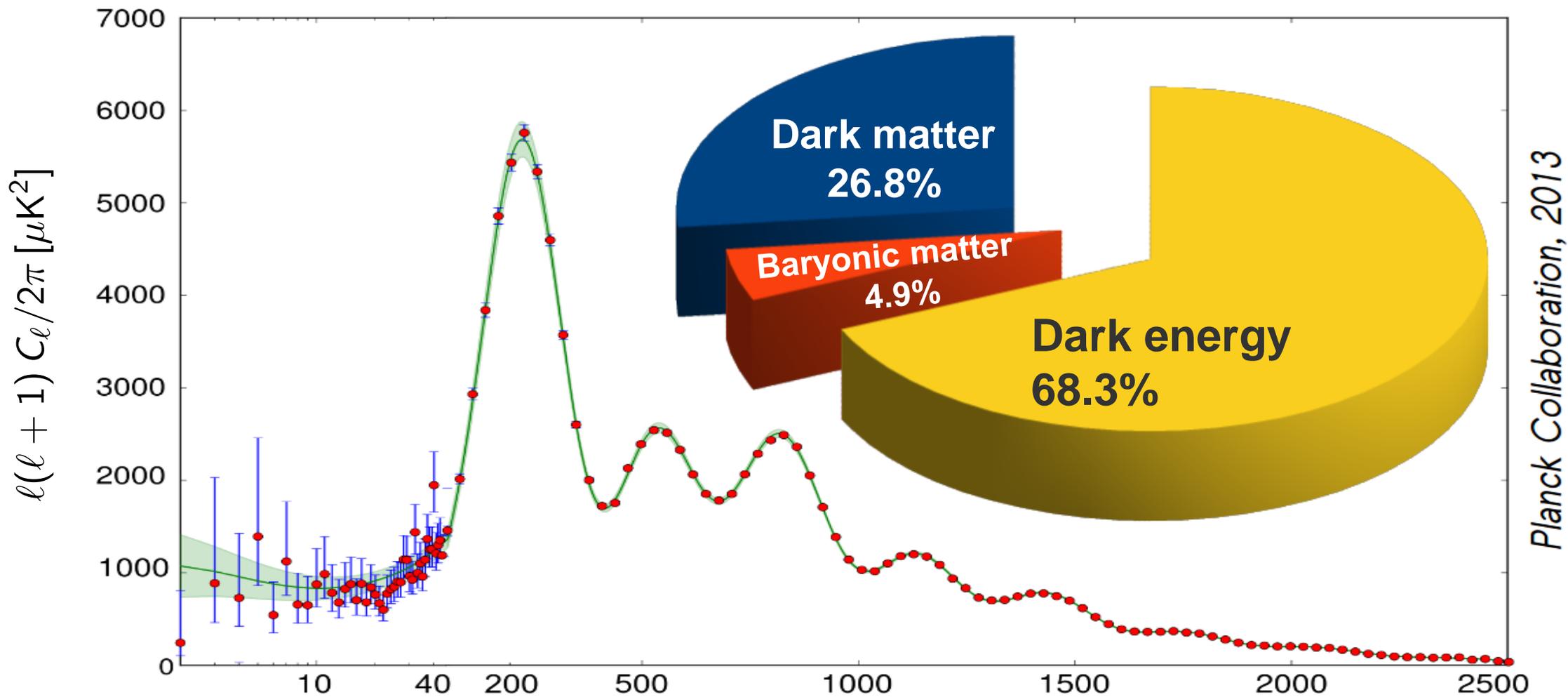
Spherical harmonics



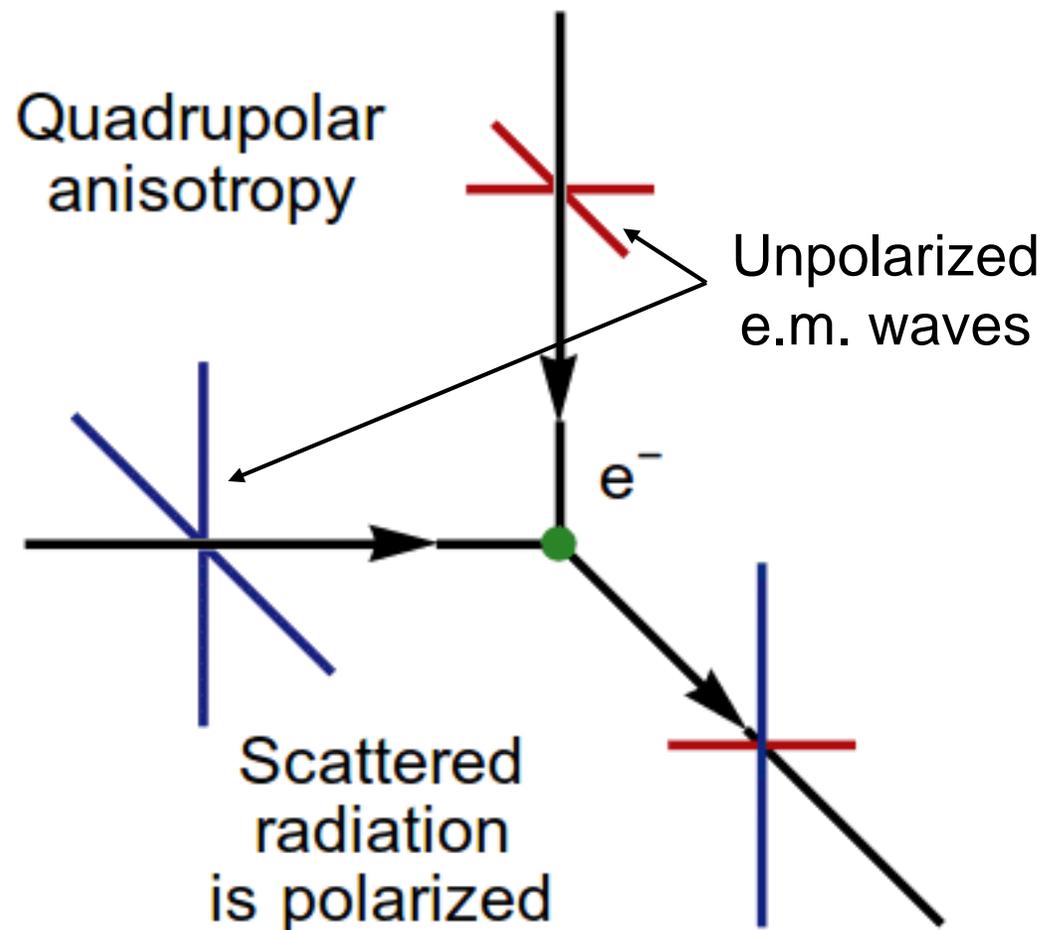
Spherical harmonics



Λ CDM universe



Thomson scattering and polarization

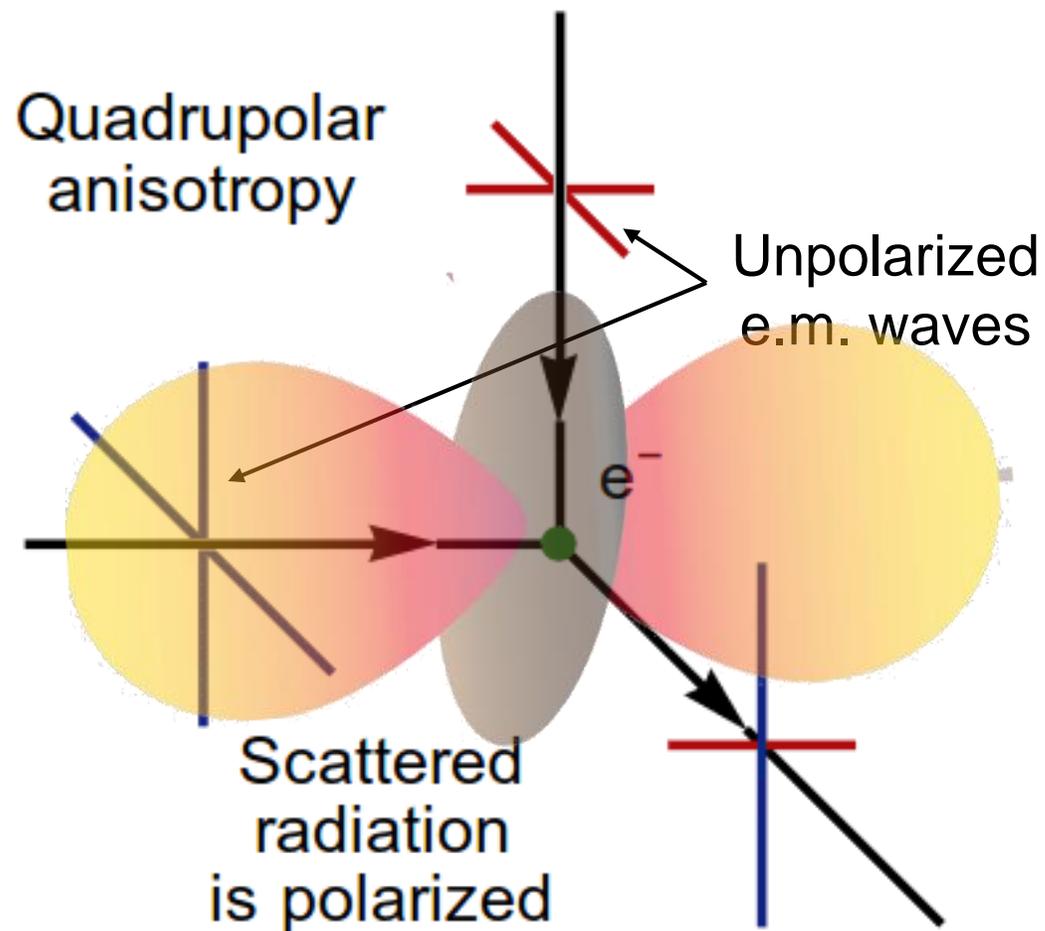


The CMB is partially polarized because of Thomson scattering in an anisotropic environment

In particular partial polarization is possible only if the CMB possesses a non zero quadrupolar anisotropy

What are the mechanisms that generate a quadrupolar moment?

Thomson scattering and polarization



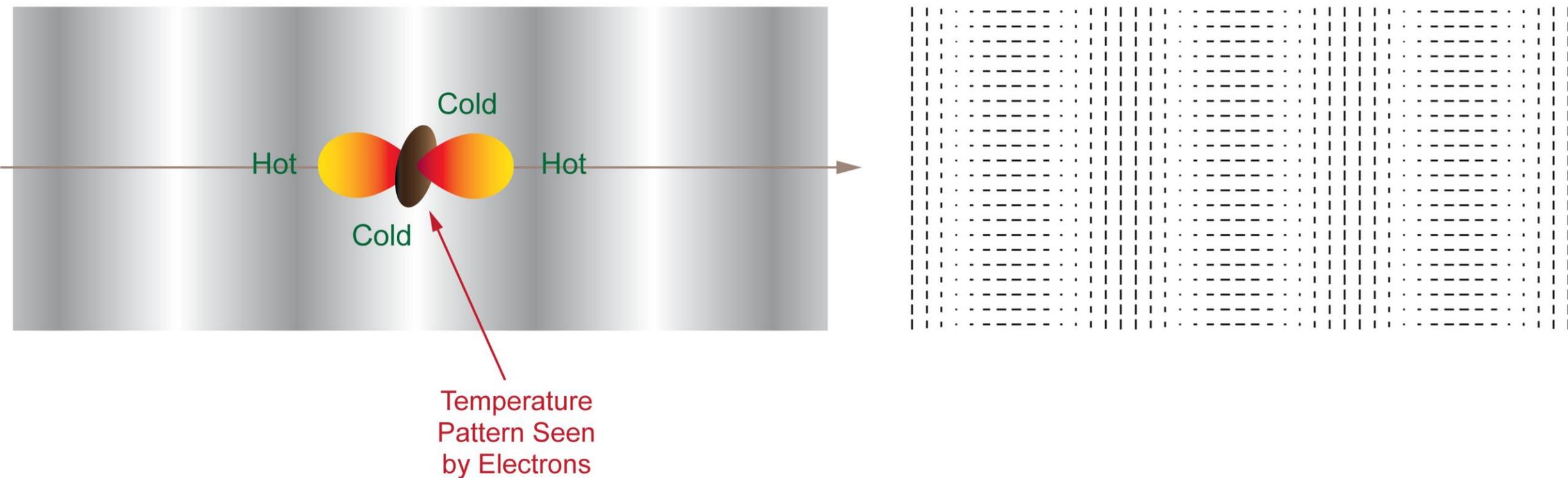
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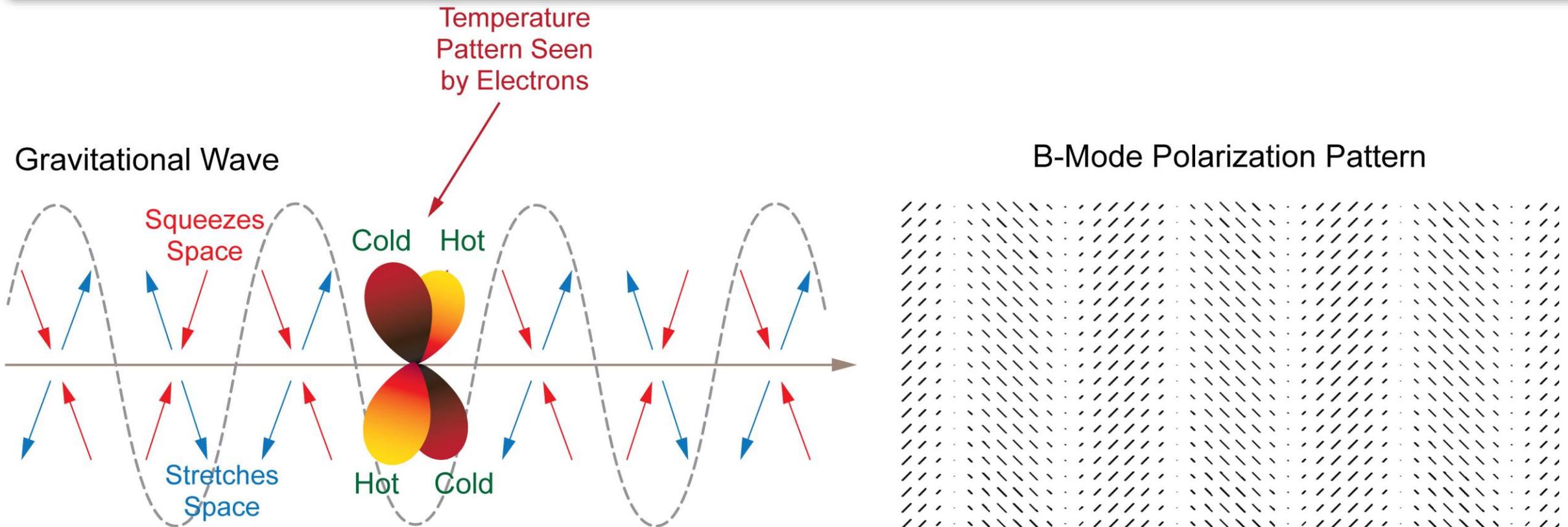
The effect of density (scalar) perturbations

A quadrupolar anisotropy caused by density perturbations generates a so-called E-mode pattern (polarization direction is parallel to crests and perpendicular to troughs)

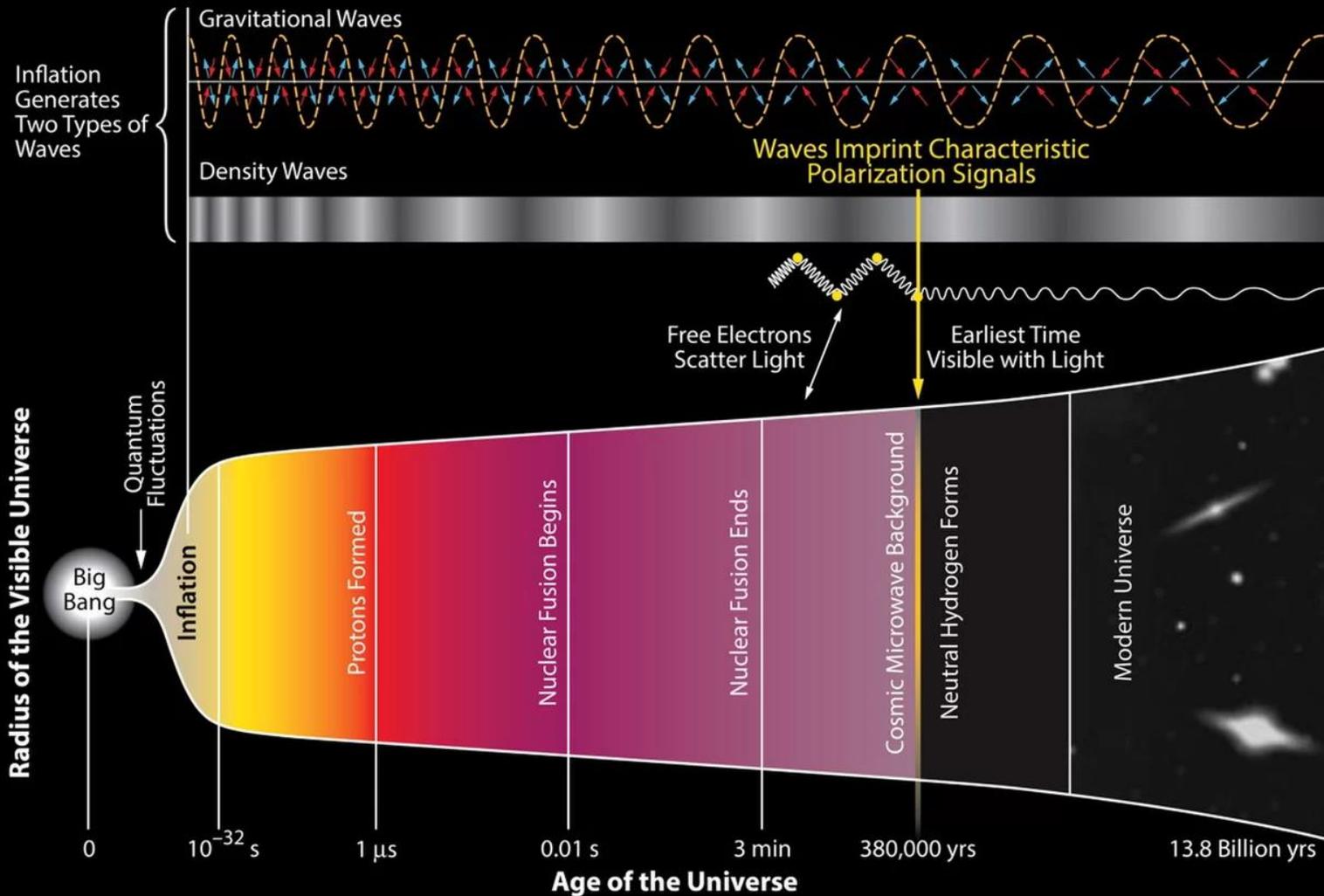


The effect of gravity (tensor) perturbations

A quadrupolar anisotropy caused by gravity waves can generate either E-modes or B-modes (in the figure) depending on the orientation of the *stretch and squeeze* pattern with respect to the line-of-sight (parallel to crests and perpendicular to troughs)



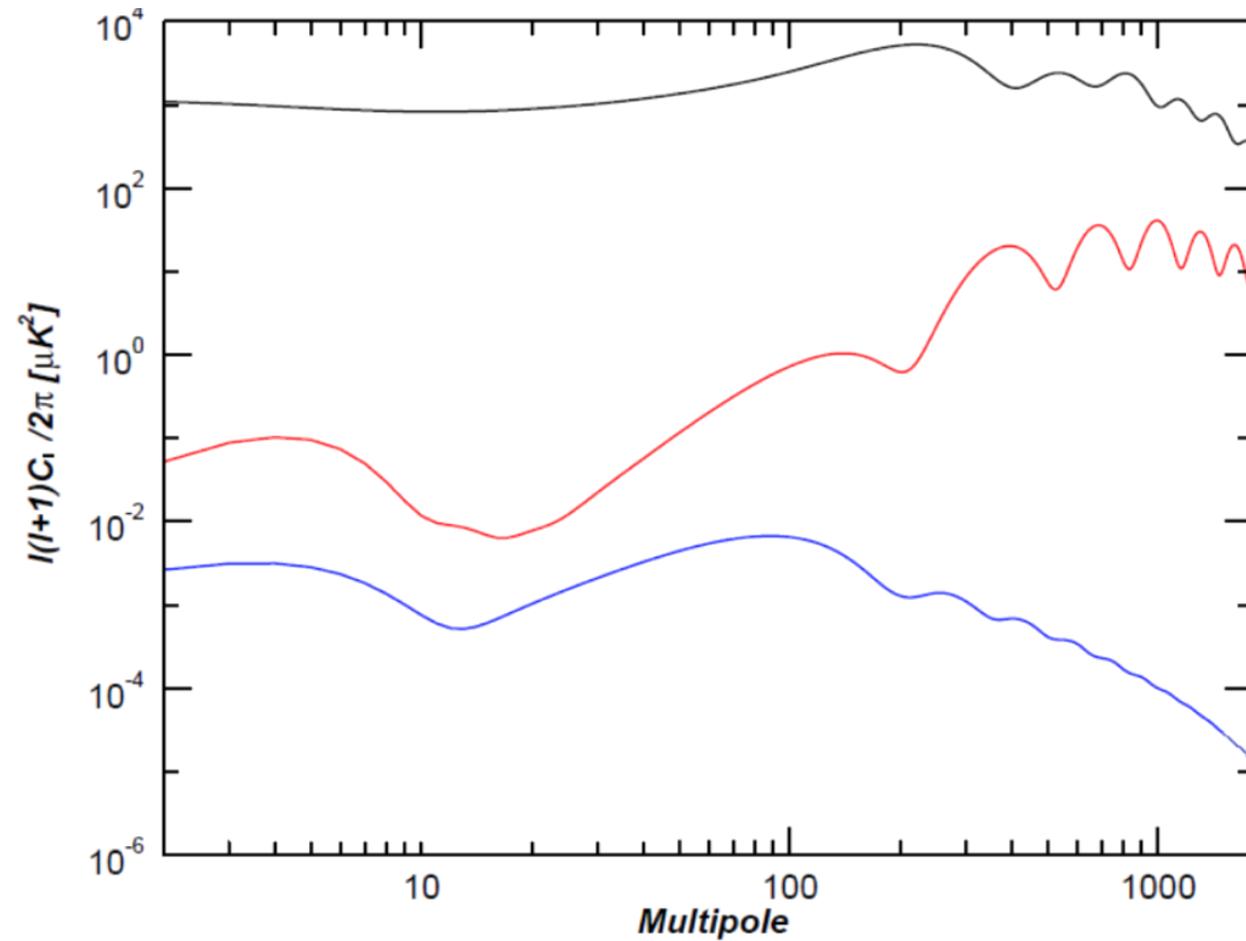
Inflation and primordial gravity waves



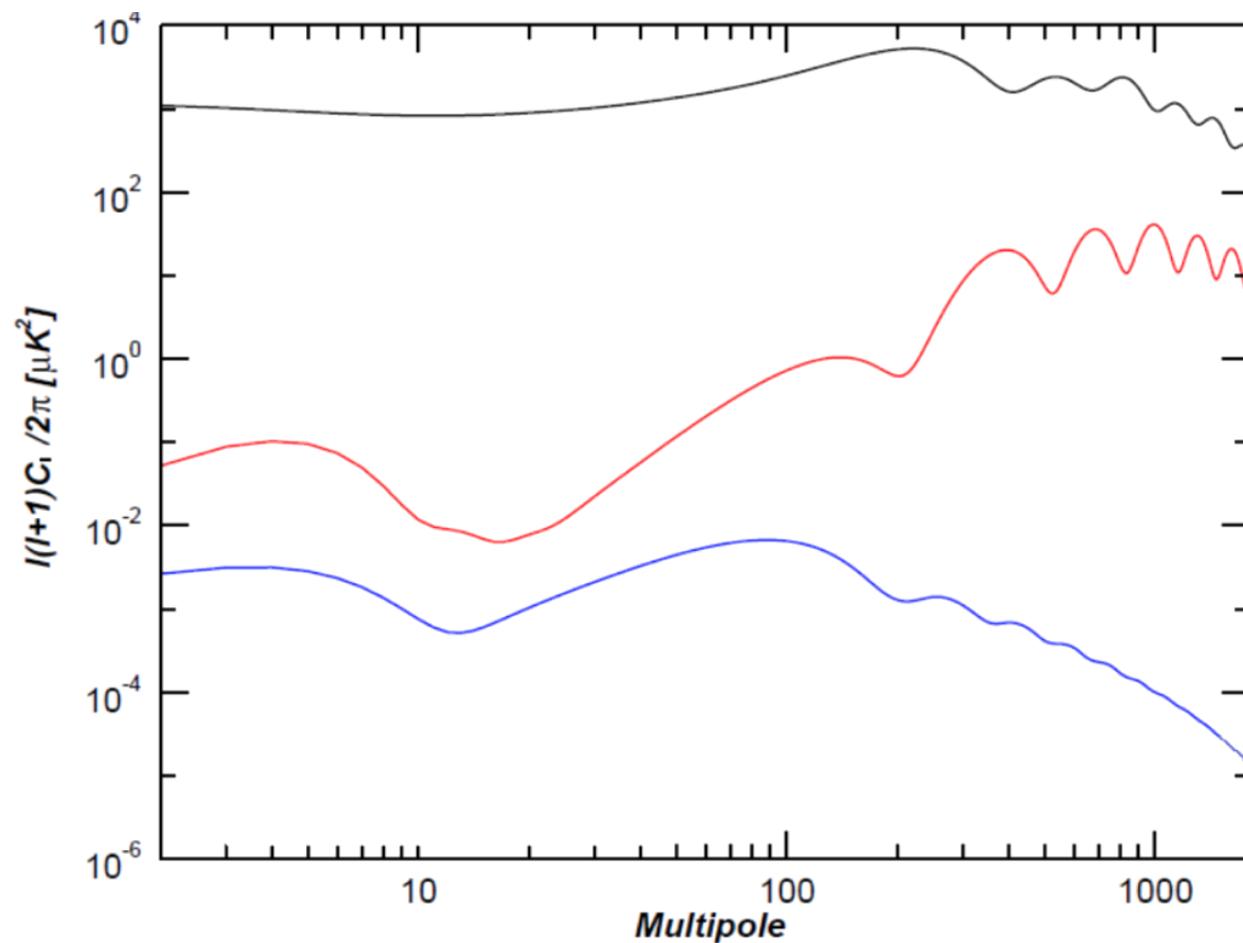
The inflationary paradigm predicts the existence of both scalar and tensor perturbations.

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

Angular power spectra

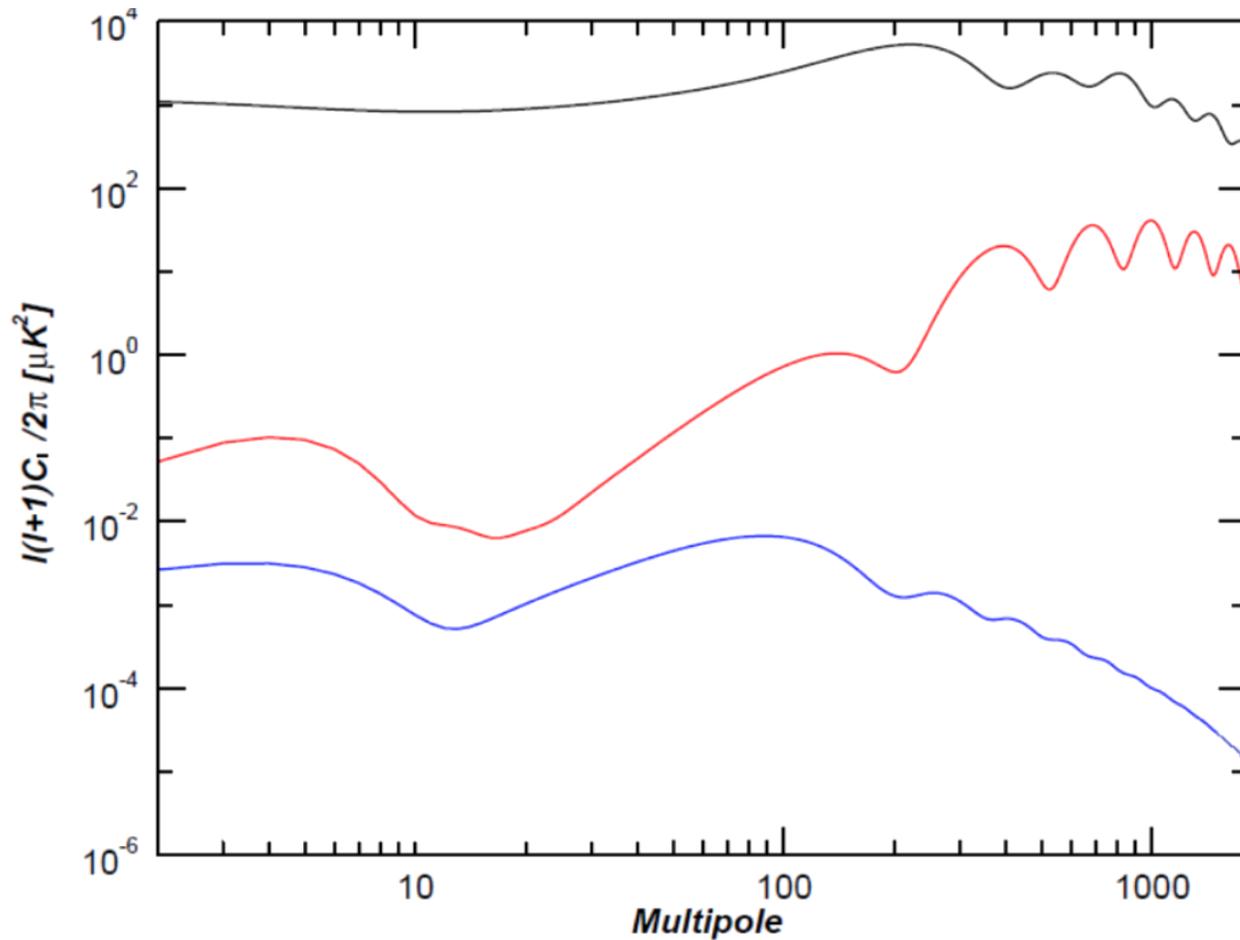


Angular power spectra



Total intensity: measured with *ultimate* precision

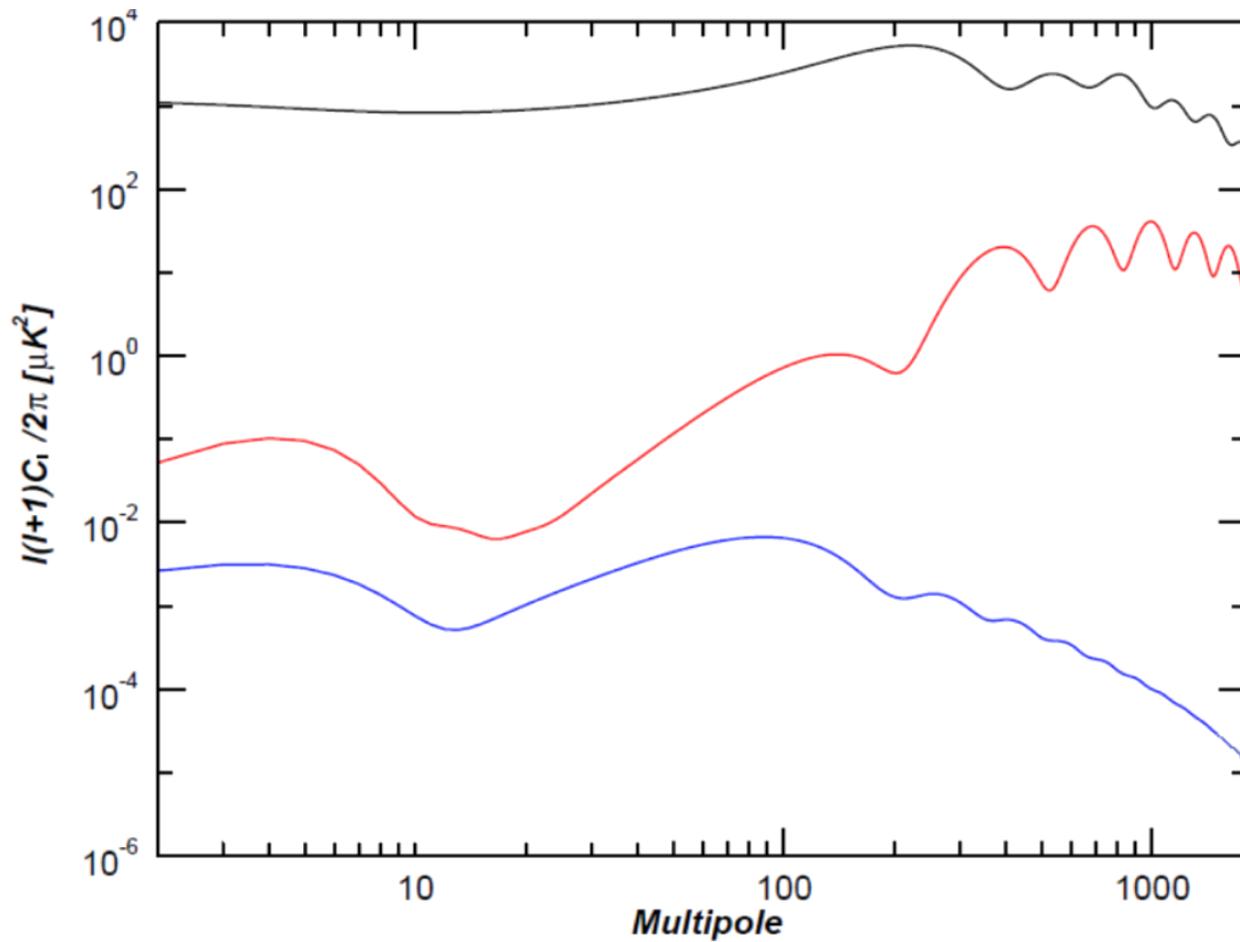
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E-modes: measured *very* precisely

Angular power spectra

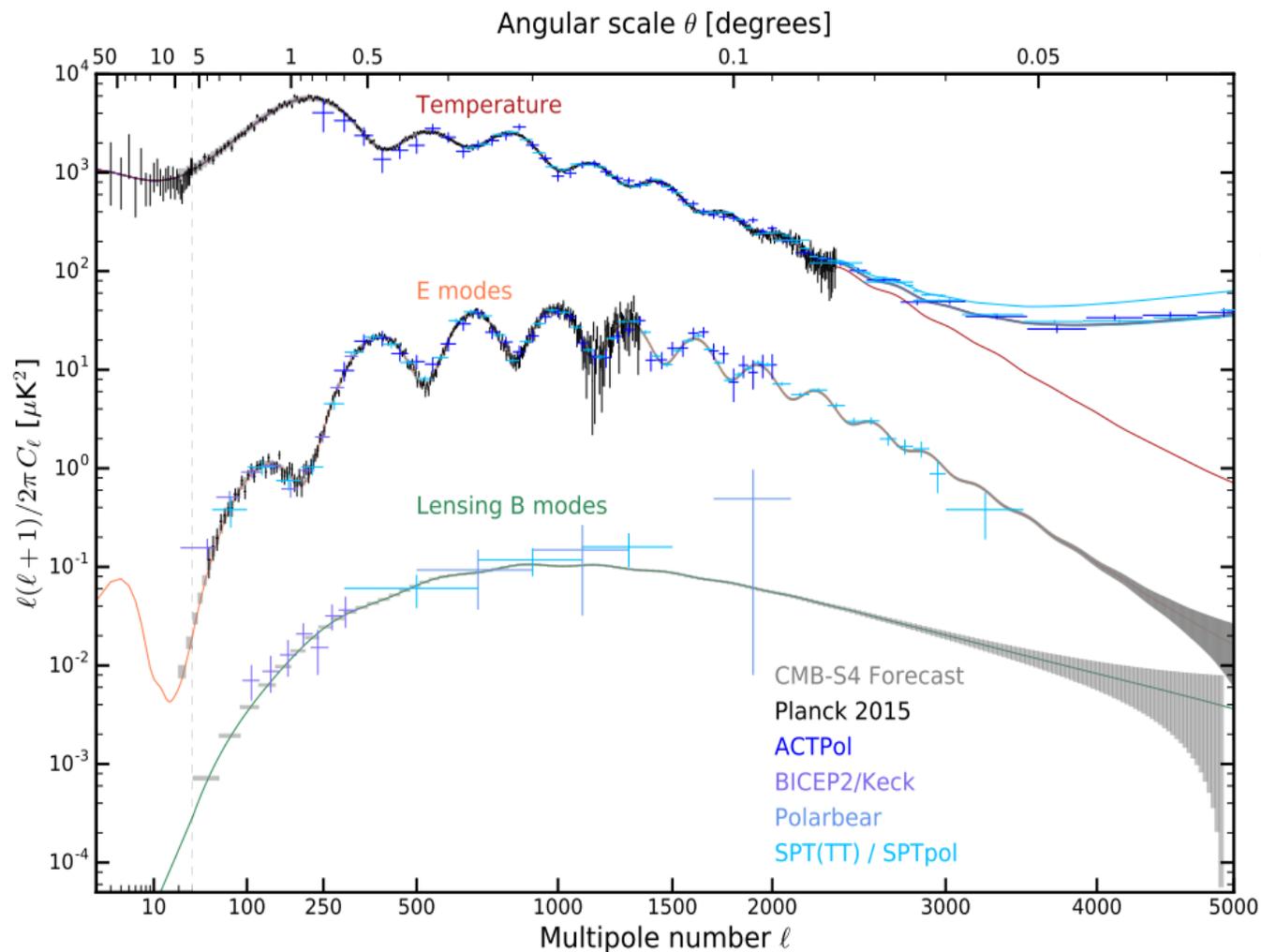


Total intensity: measured with *ultimate* precision

E-modes: measured *very* precisely

B-modes: undetected. Level not constrained by inflationary theories

Measurements state of the art

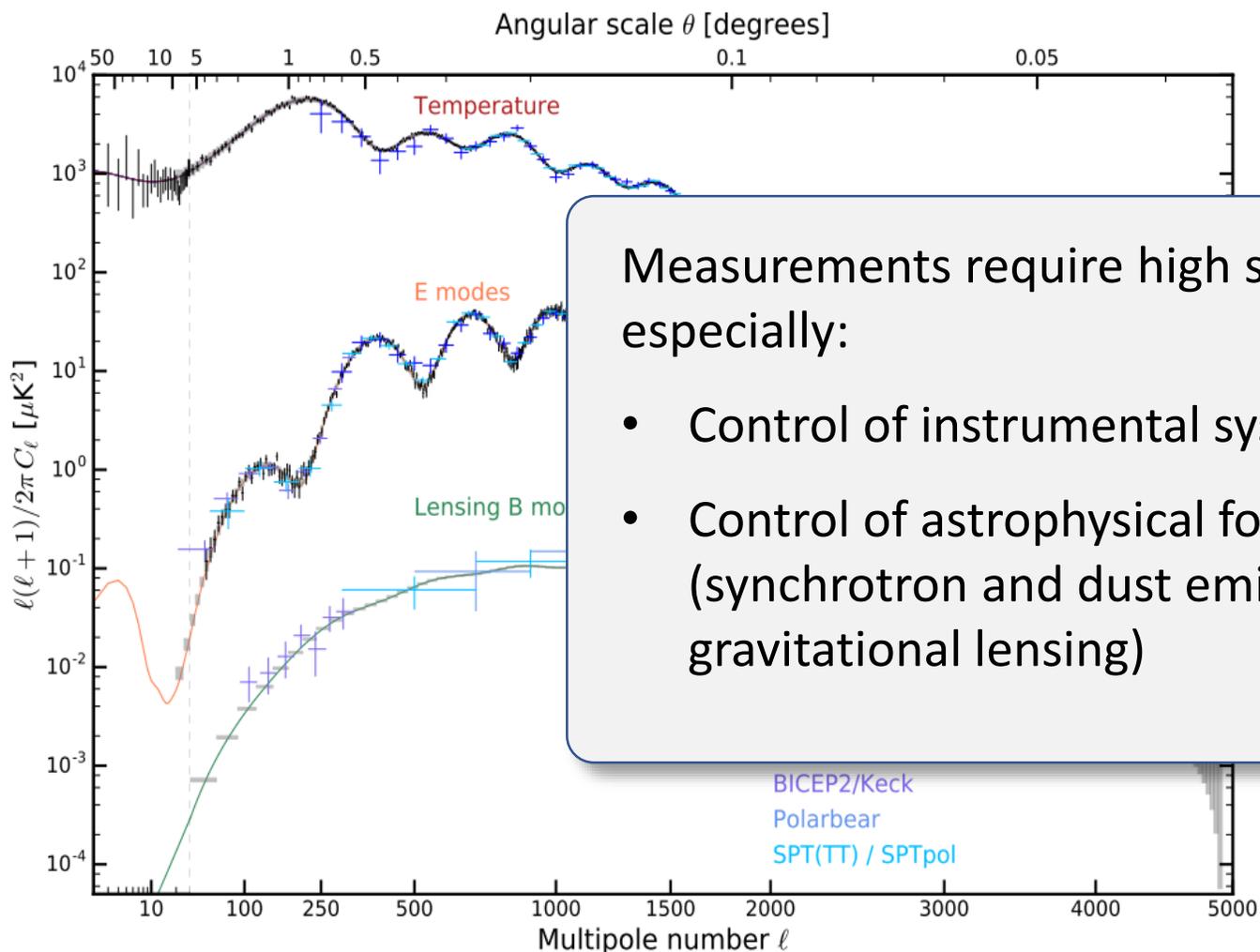


Total intensity: measured with *ultimate* precision

E-modes: measured *very* precisely

B-modes: current measurements have detected only those caused by gravitational lensing (which act as a systematic effect)

Measurements state of the art



Measurements require high sensitivity but, especially:

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

measured with *ultimate*

and very precisely

Measurements have detected only those caused by gravitational lensing (which act as a systematic effect)

Worldwide competition

Project	Country	Location	Status	Frequencies (GHz)	ℓ range		$\sigma(r)$ goal	
					value	Ref.	no fg.	with fg.
QUBIC	France	Argentina	2018	150,220	30-200		0.006	0.01
Bicep3/Keck	U.S.A.	Antartica	Running	95, 150, 220 ¹	50-250	[22]	2.5 10^{-3}	0.013
CLASS	U.S.A.	Atacama	> 2017	38, 93, 148, 217	2-100	[29]	1.4 10^{-3}	0.003
SPT3G	U.S.A.	Antartica	2017	95, 148, 223	50-3000	[23]	1.7 10^{-3}	0.005
AdvACT	U.S.A.	Atacama	Starting	90, 150, 230	60-3000	[24]	1.3 10^{-3}	0.004
Simons Array	U.S.A.	Atacama	\geq 2017	90, 150, 220	30-3000	[25]	1.6 10^{-3}	0.005
LSPE	Italy	Arctic flight + Tenerife	2018	43, 90, 140, 220, 245	3-150	[30]		0.03
EBEX10K	U.S.A.	Antartica	\geq 2017	150, 220, 280, 350	20-2000	[28]	2.7 10^{-3}	0.007
SPIDER	U.S.A.	Antartica	Running	90, 150	20-500	[26]	3.1 10^{-3}	0.012
PIPER	U.S.A.	Multiple	2017?	200, 270, 350, 600	2-300	[27]	3.8 10^{-3}	0.008

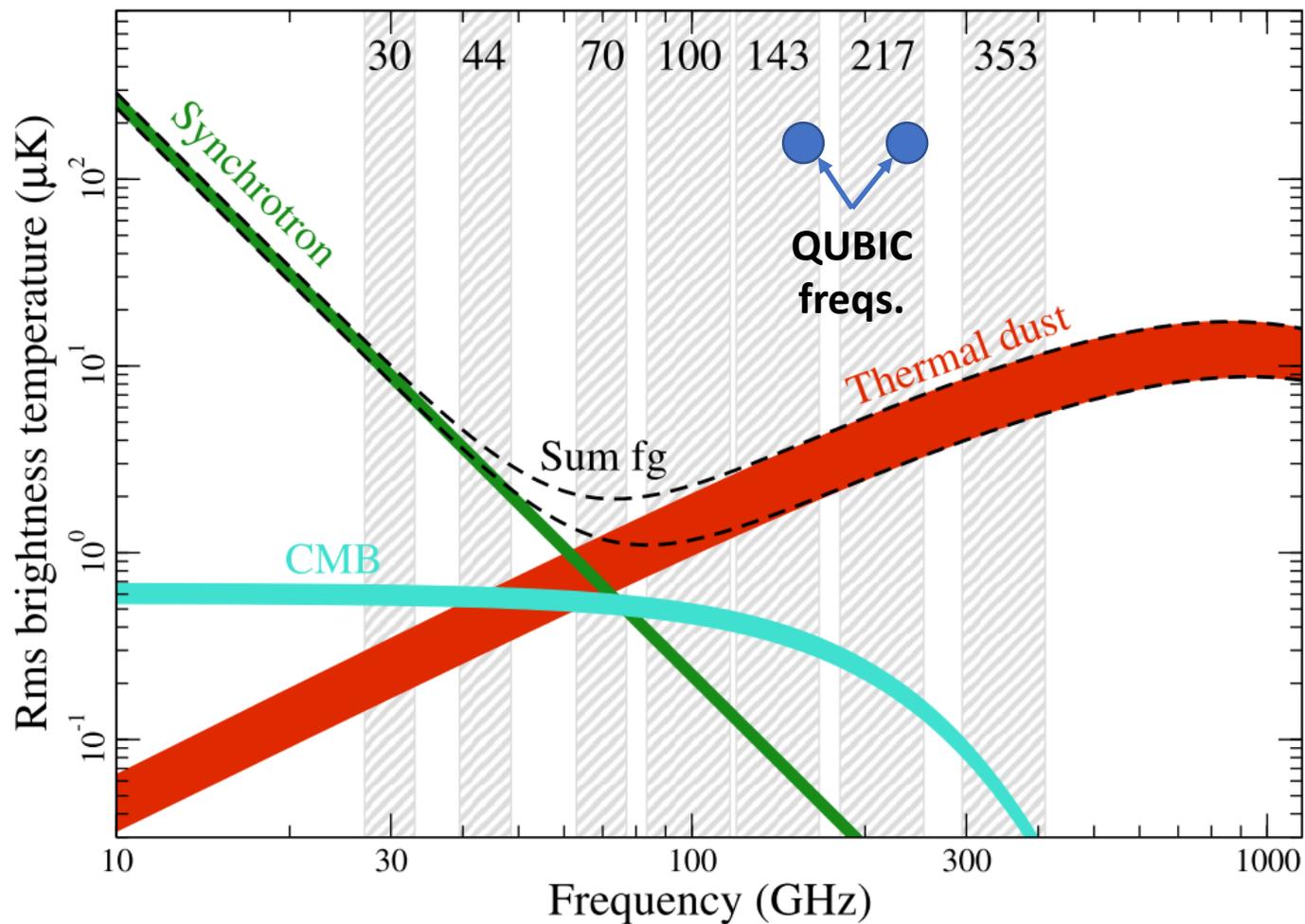
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+ Simons observatory, 2016 – 2021, funded (~ 40 M\$)

+ CMB S4, 2020 – 2024, not funded yet

Foreground control

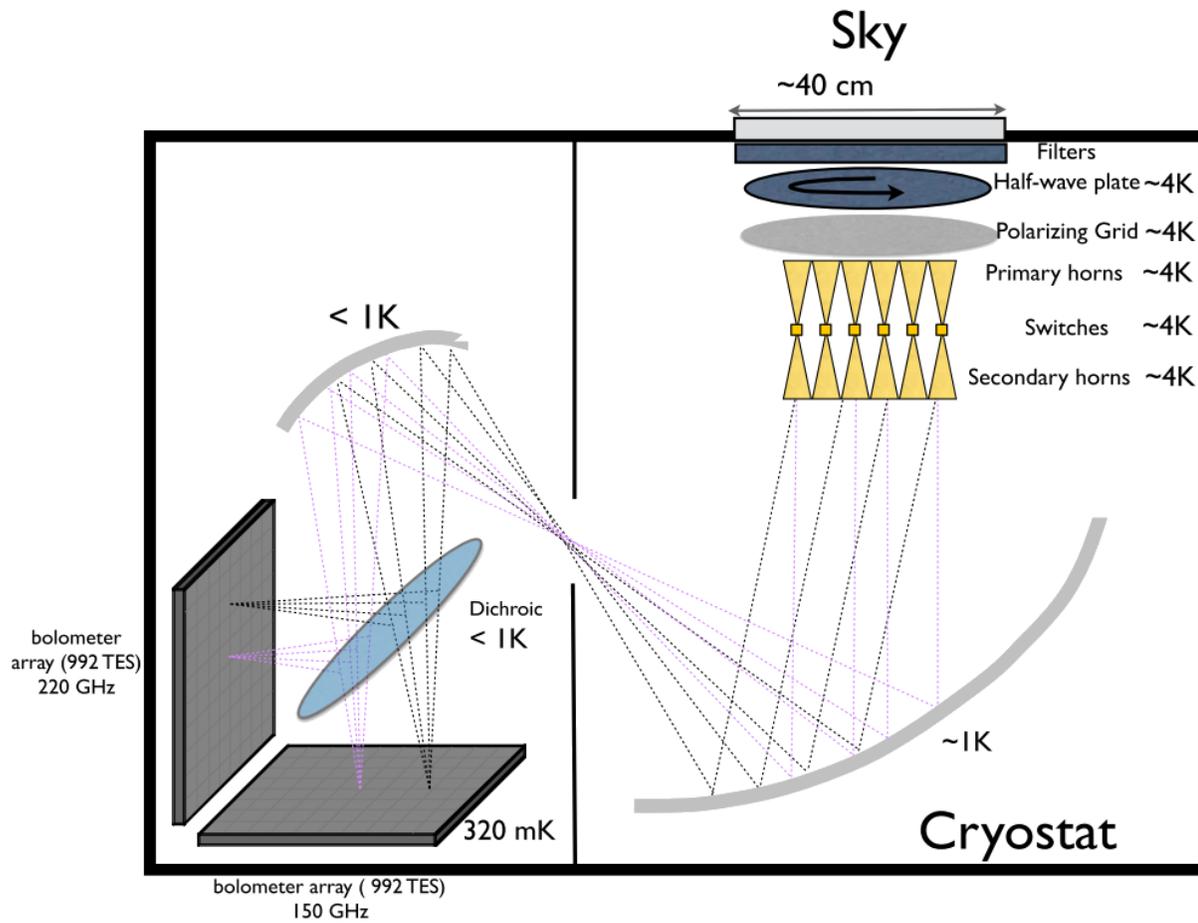


QUBIC frequencies

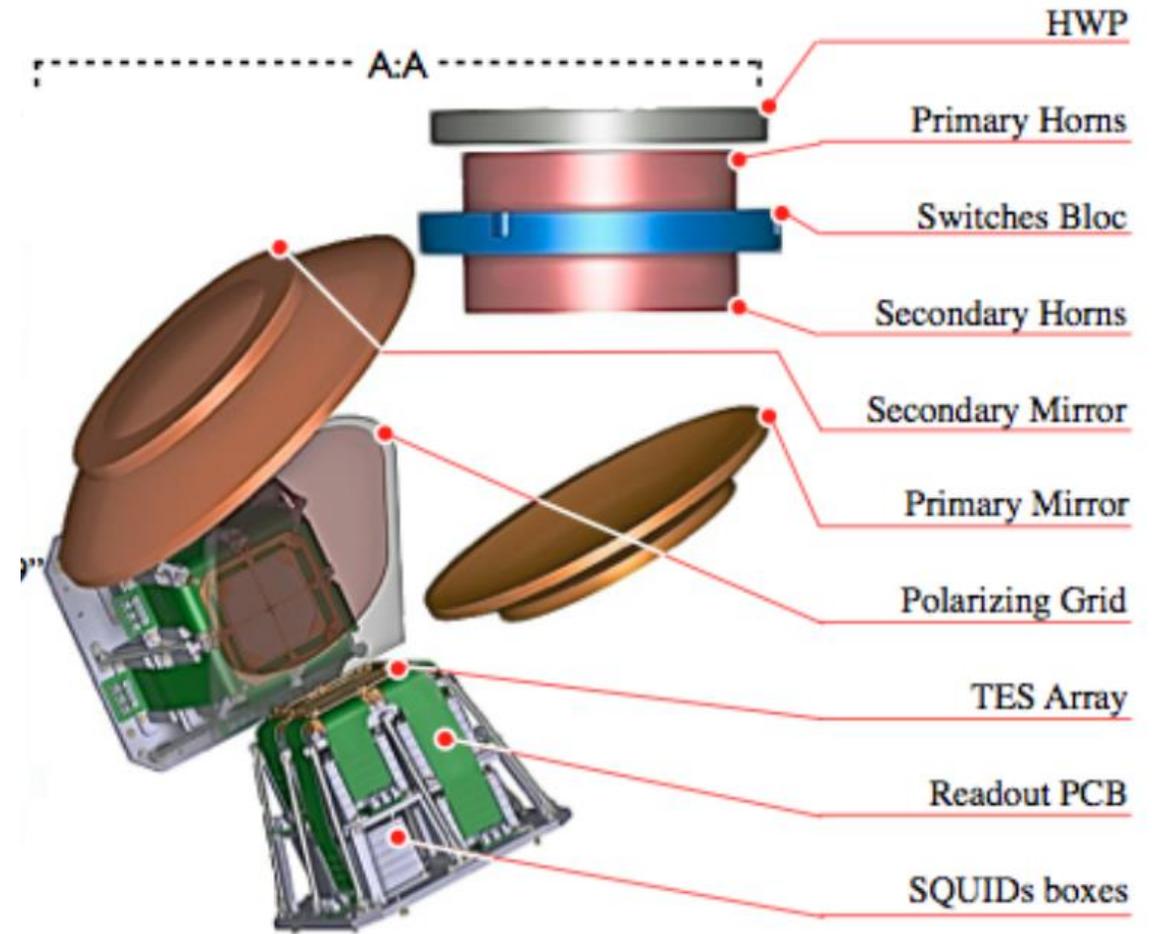
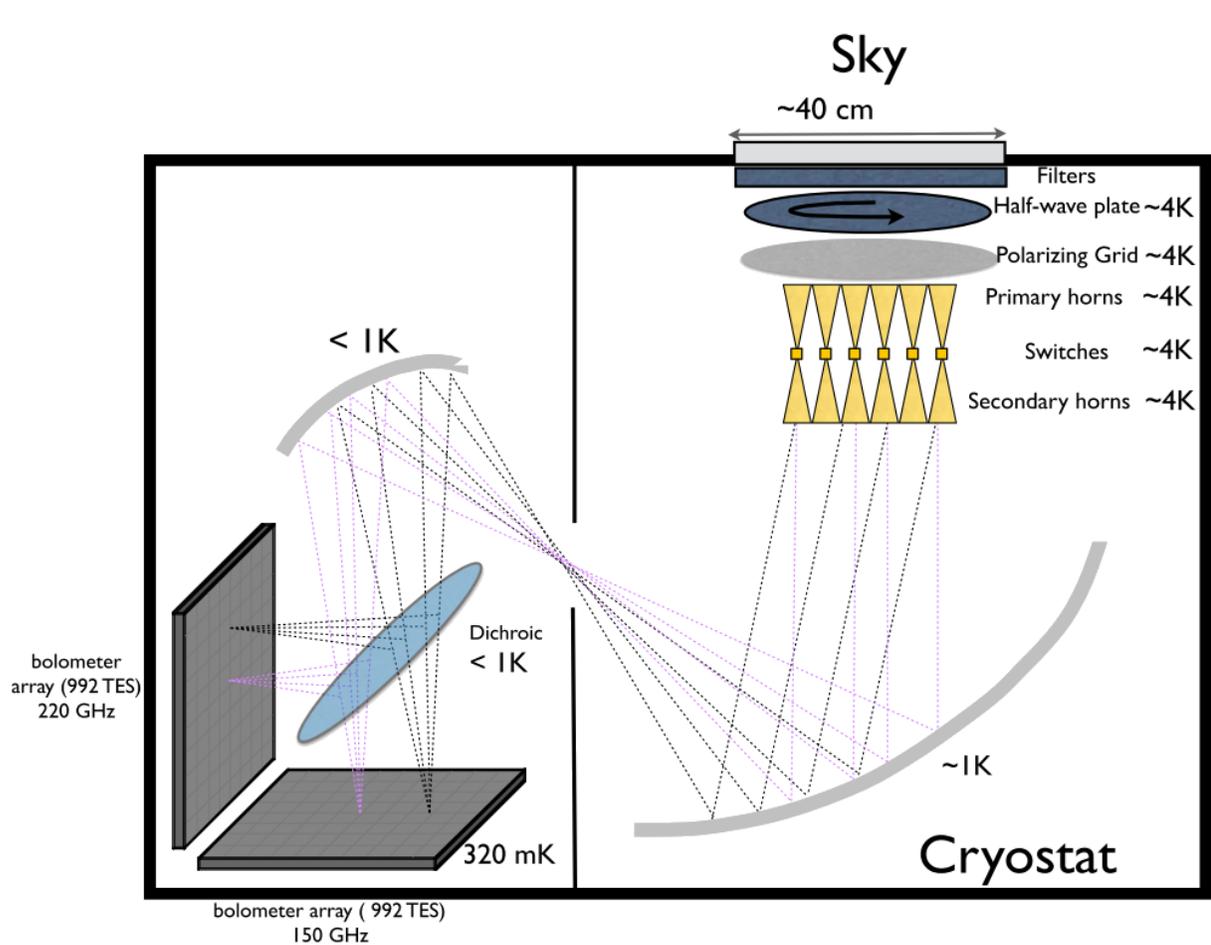
- QUBIC will observe in a small patch of the sky relatively “clean” of foregrounds
- Dust contamination will be evaluated by measuring at two frequencies and exploiting existing data like Planck

Planck collaboration et al, 2015, A&A, 594, A10

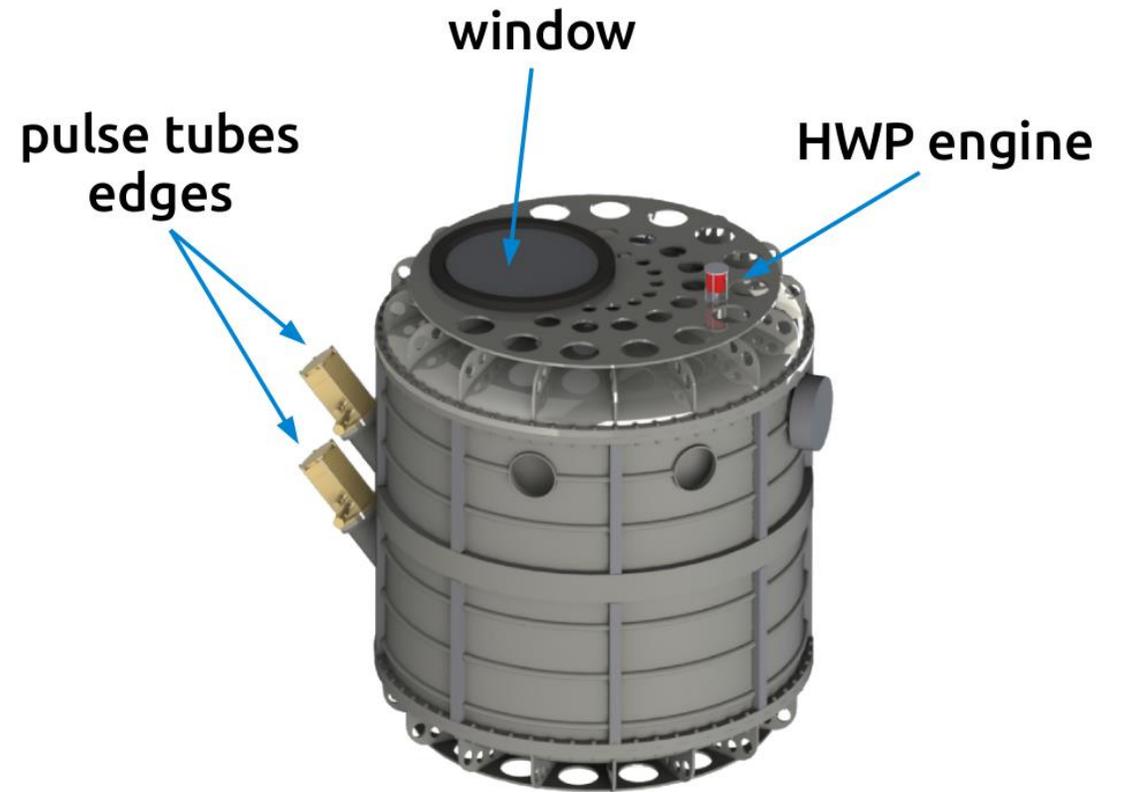
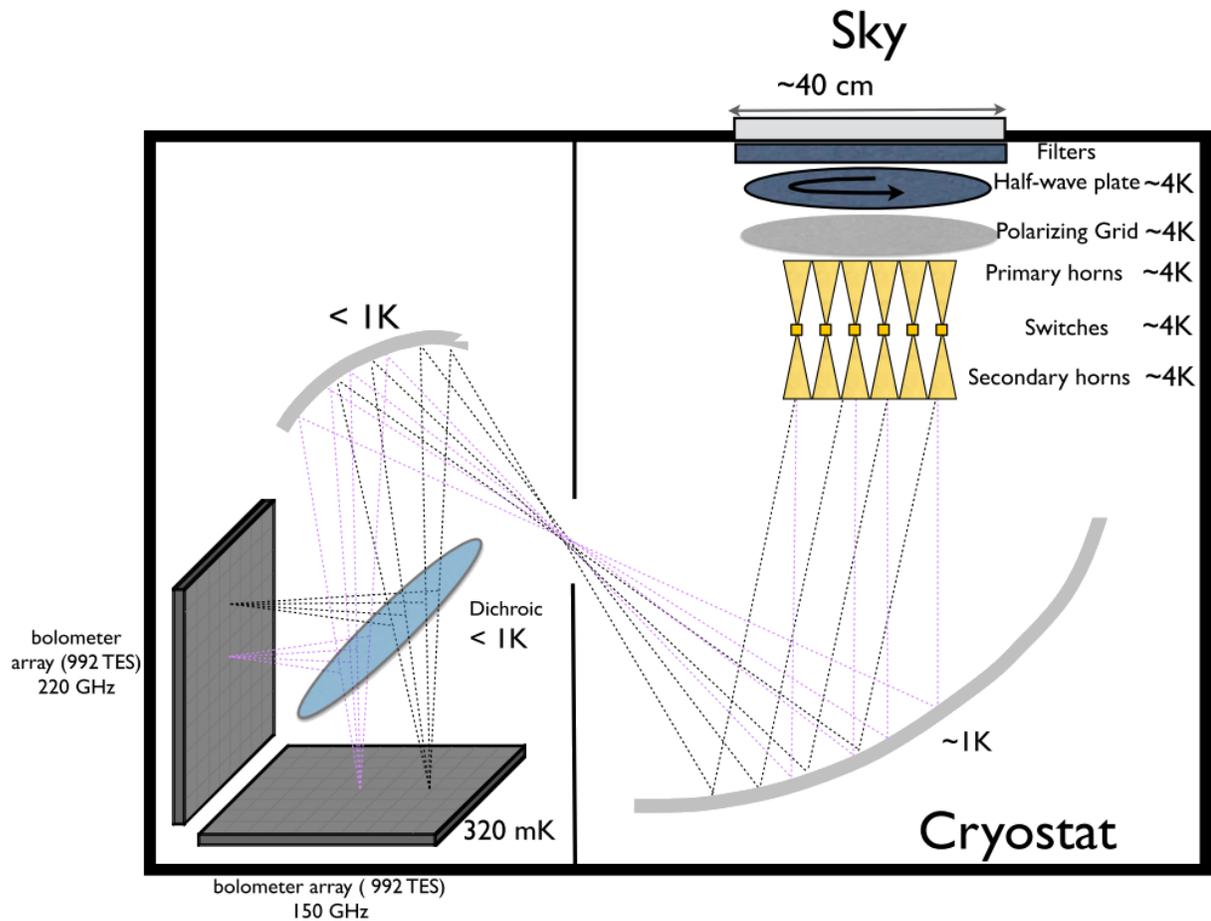
QUBIC in a nutshell – the instrument



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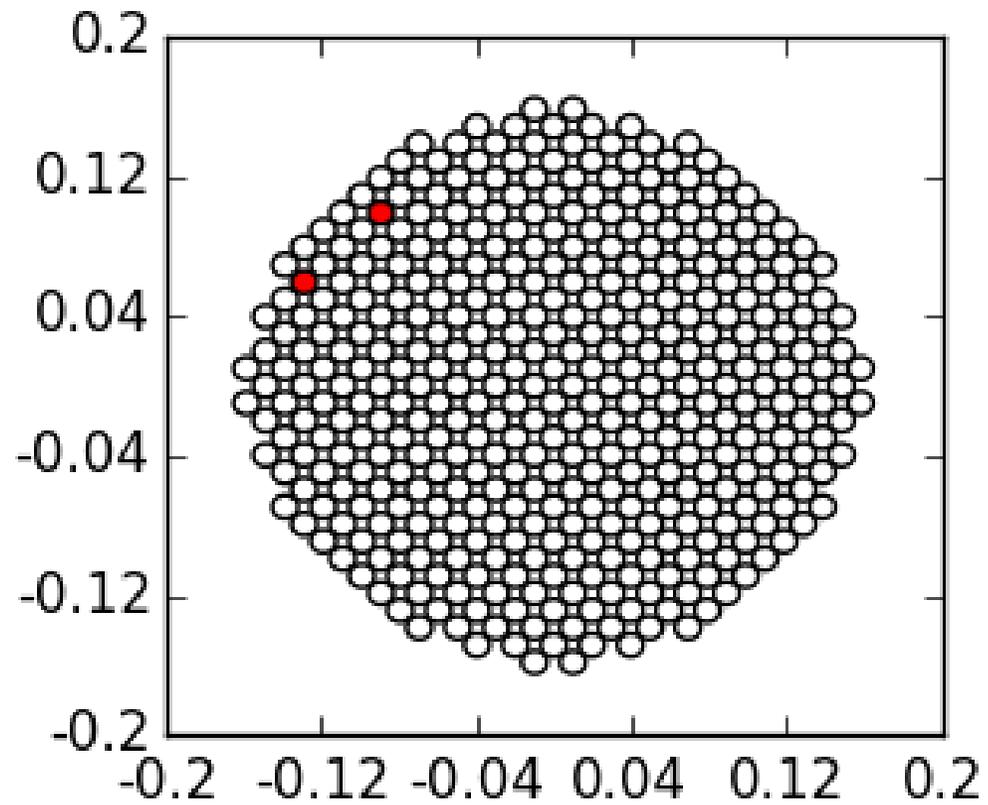


QUBIC in a nutshell – the instrument



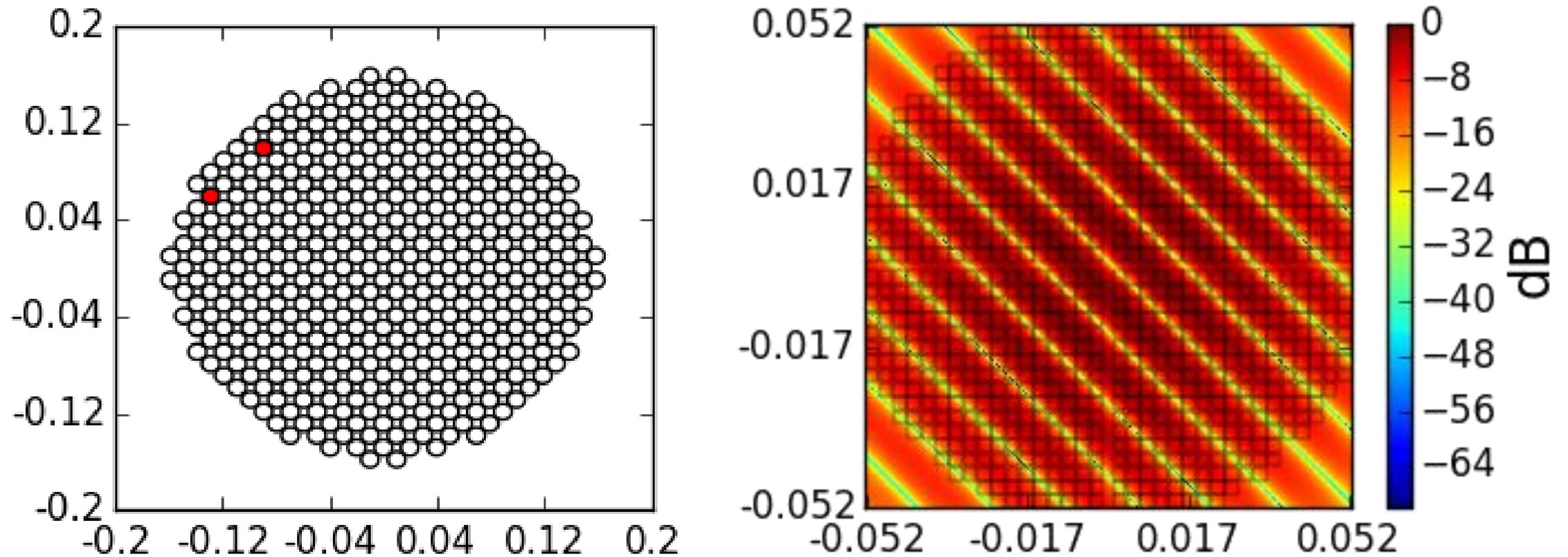
QUBIC in a nutshell – the measurement

Response to a point source in the far field



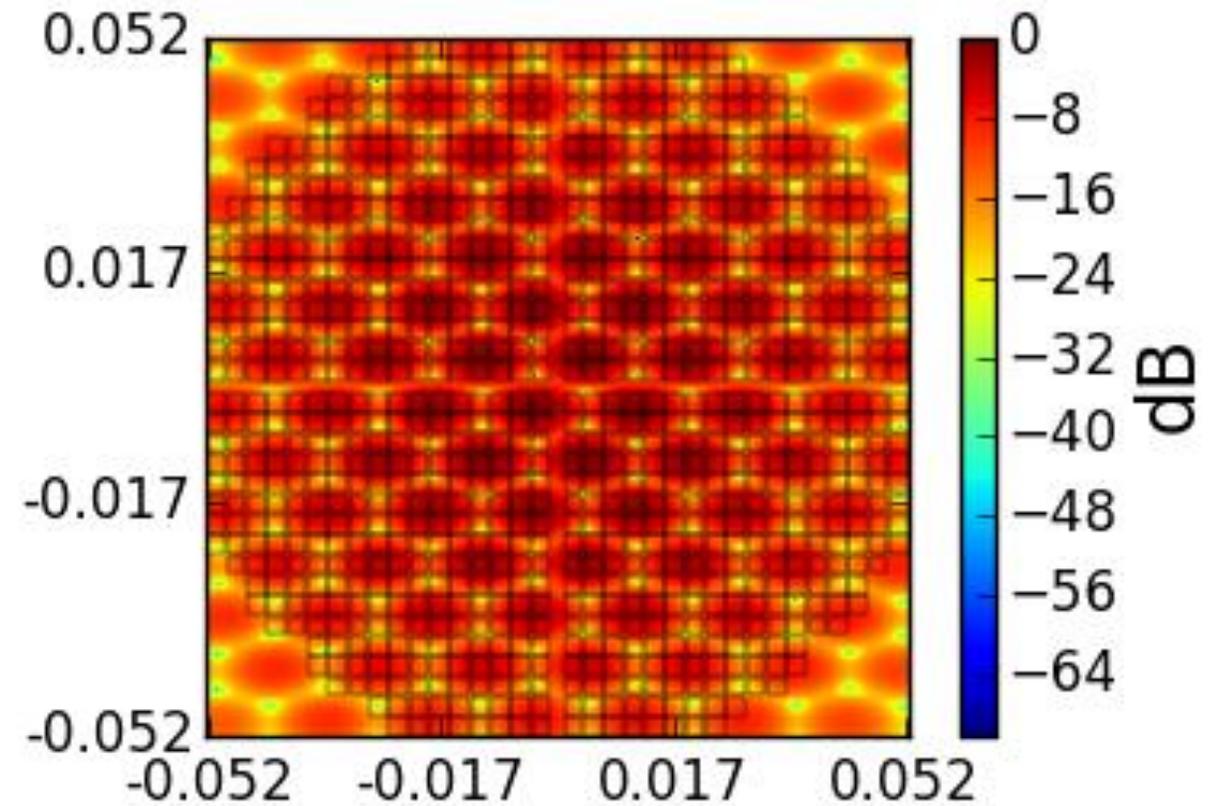
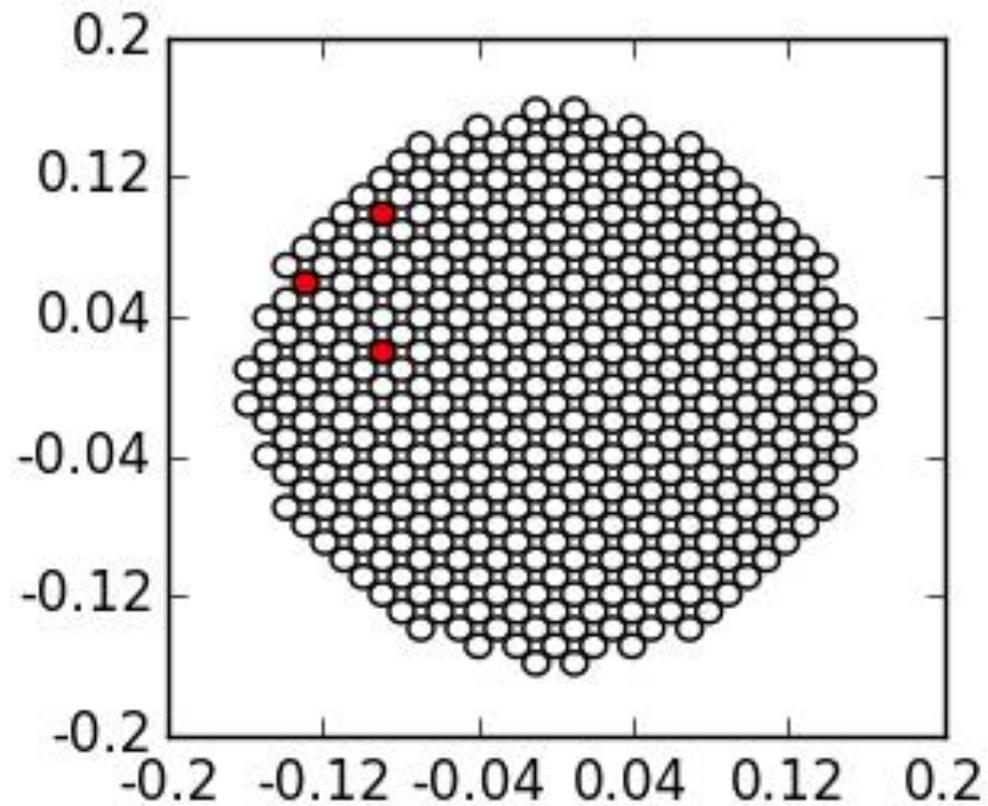
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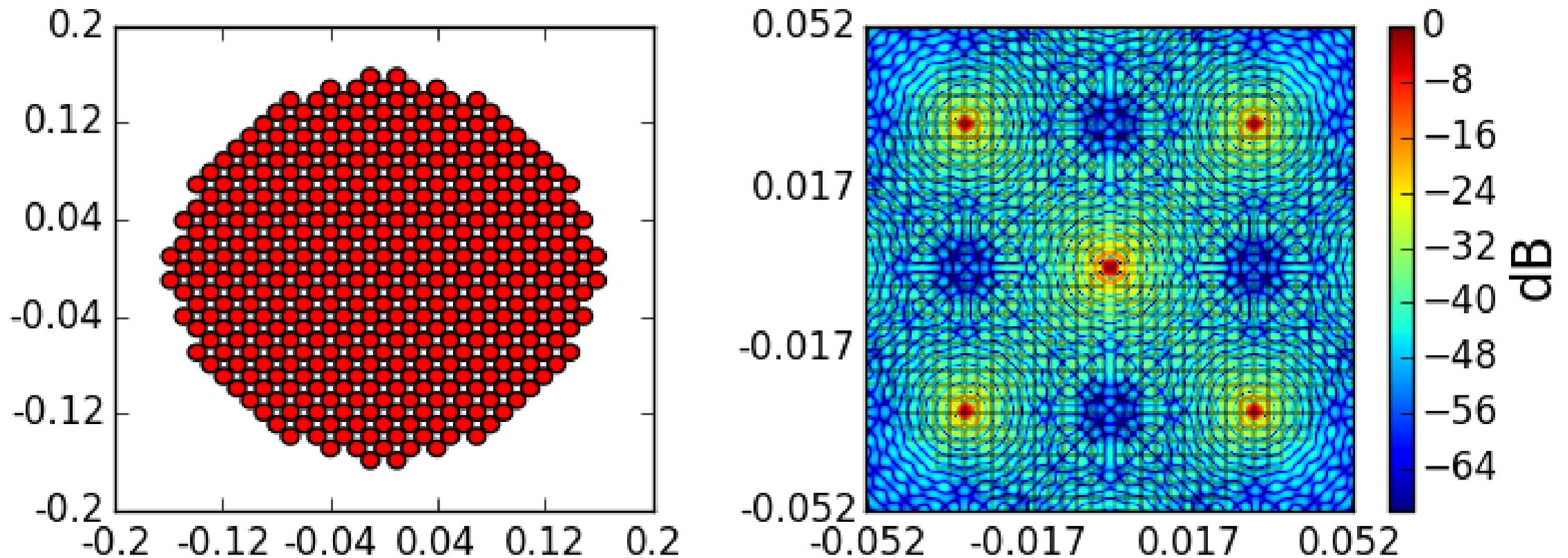
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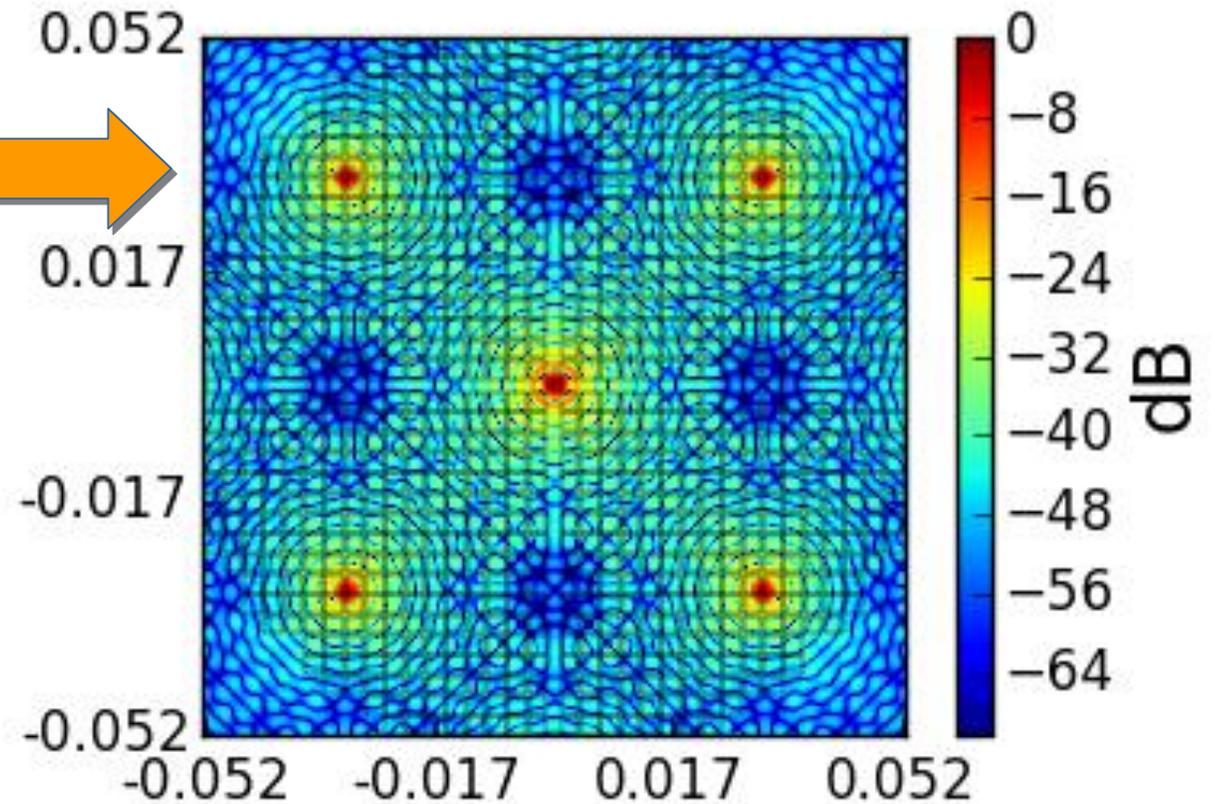
Response to a point source in the far field



QUBIC in a nutshell – the measurement

Response to a point source in the far field

Synthetized beam



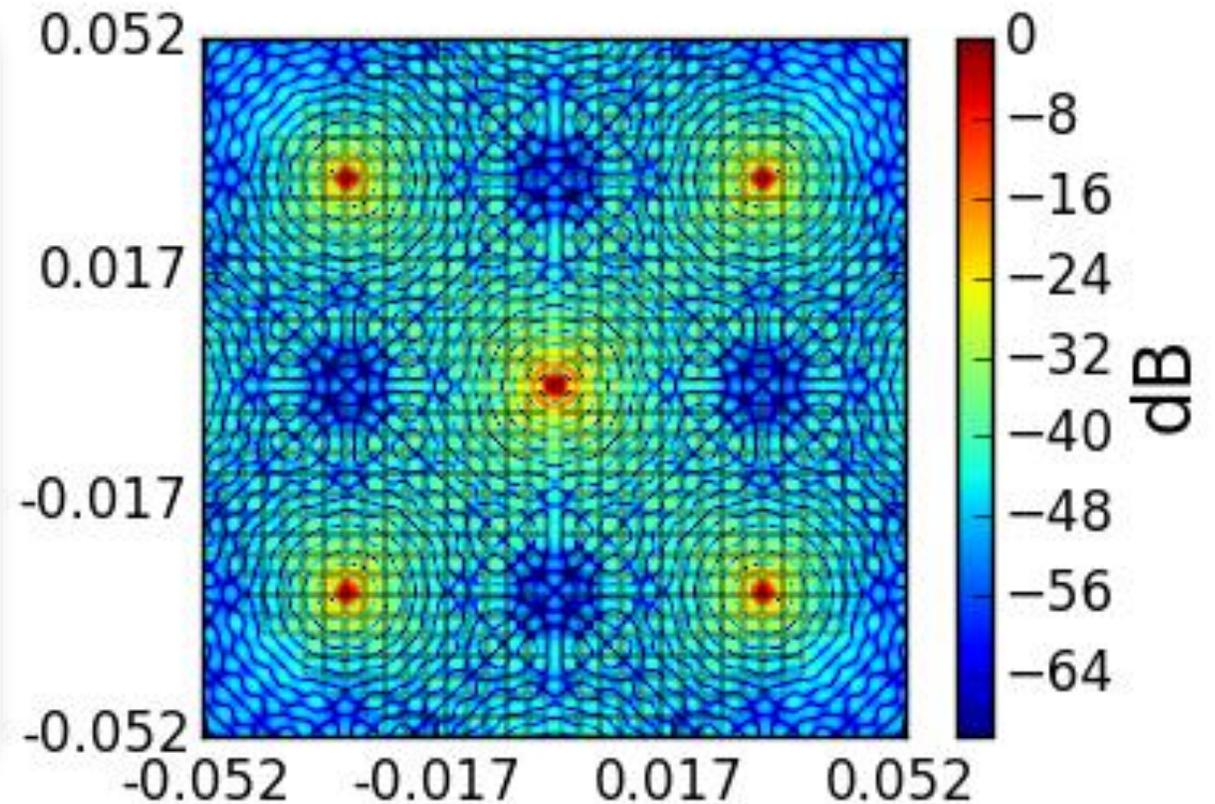
QUBIC in a nutshell – the measurement

Response to a point source in the far field

Signal measured at pixel d_p at time t

$$R(d_p, t) = S_I(d_p) + \cos(4\omega t)S_Q(d_p) + \sin(4\omega t)S_U(d_p)$$

$$S_X(d_p) = \int X(\mathbf{n})B_{\text{synth}}^p(\mathbf{n})d\mathbf{n}$$



QUBIC in a nutshell – the measurement

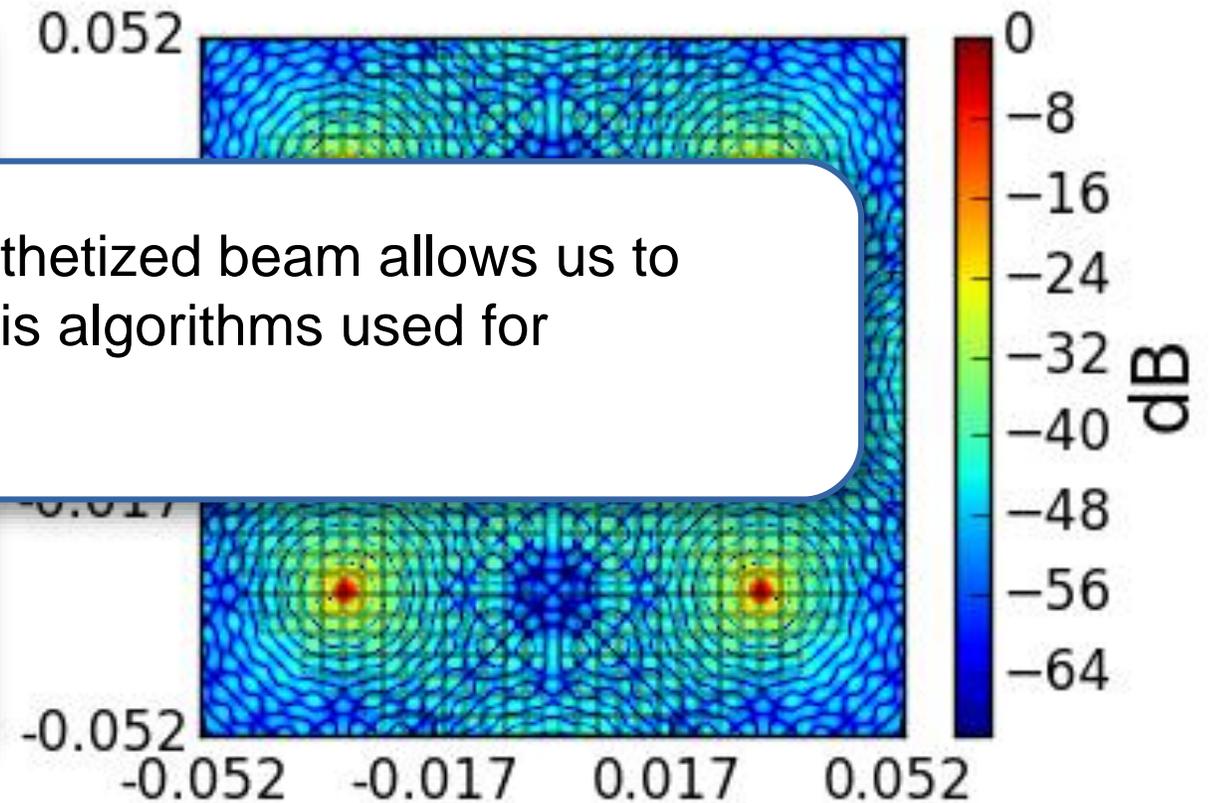
Response to a point source in the far field

Signal measured at pixel d_p at time t

$R(d_p, t)$

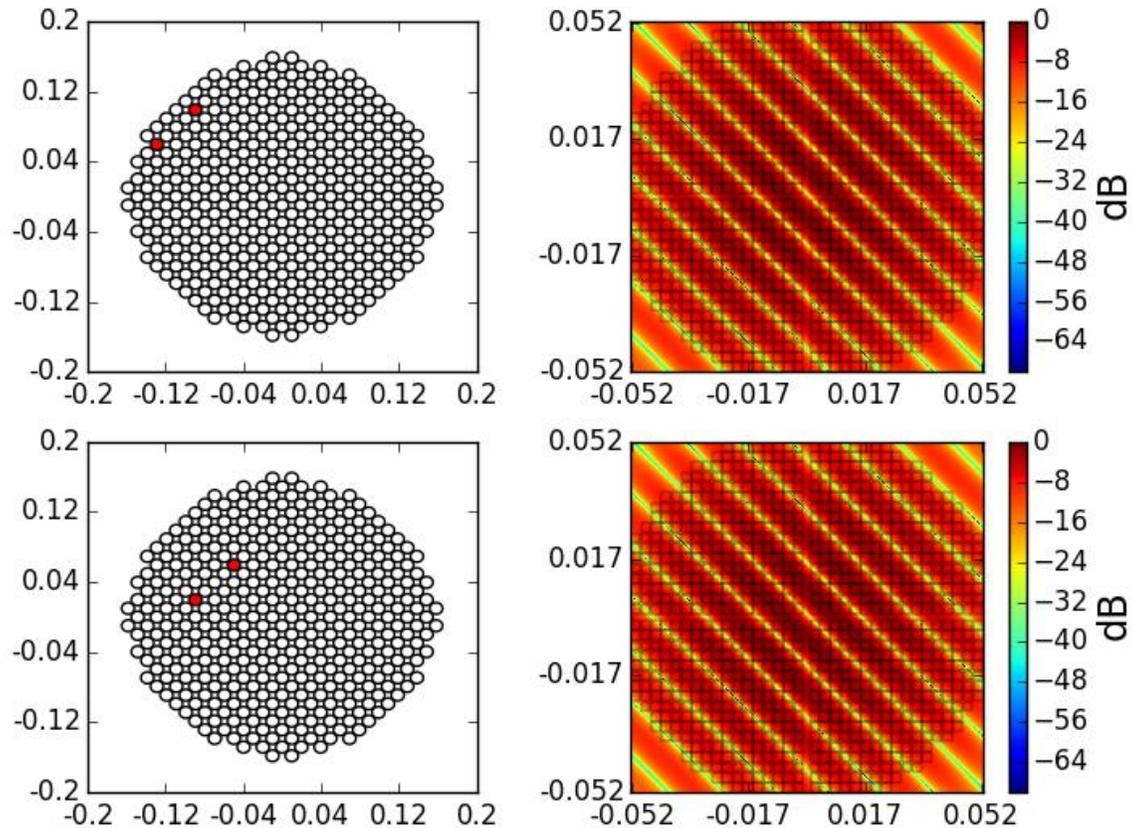
The knowledge of the synthesized beam allows us to use the same data analysis algorithms used for conventional imagers

$$S_X(d_p) = \int X(\mathbf{n}) B_{\text{synth}}^p(\mathbf{n}) d\mathbf{n}$$



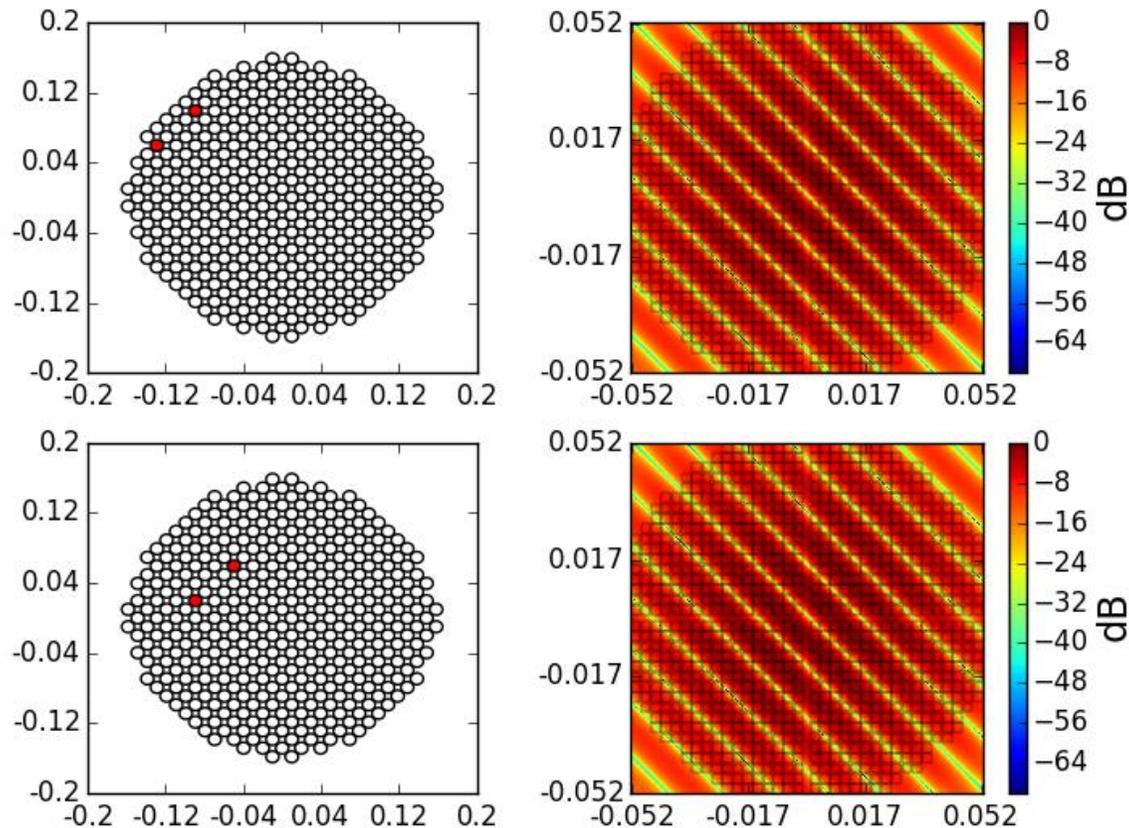
QUBIC in a nutshell – self calibration

The response from equal baselines
is in principle the same



QUBIC in a nutshell – self calibration

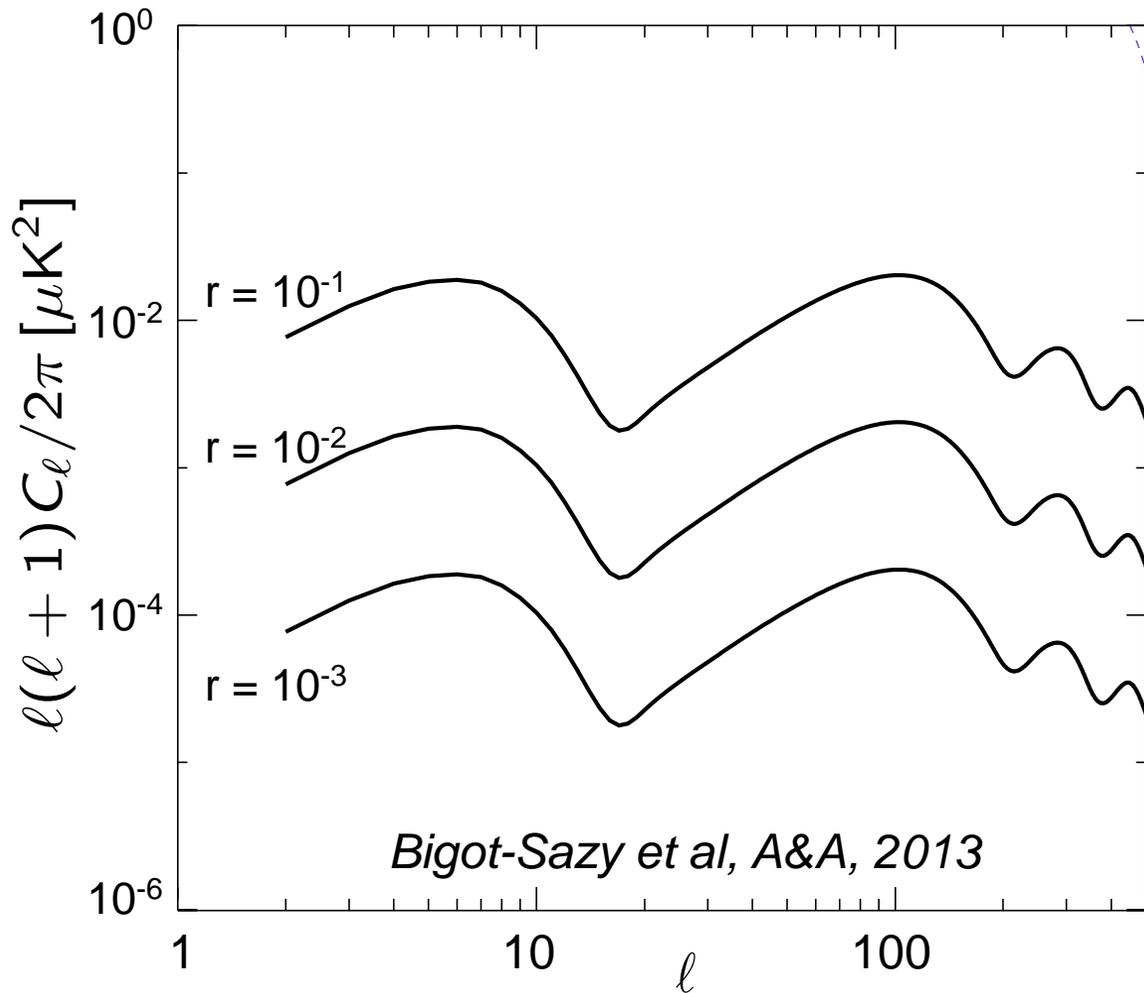
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Self calibration mode:

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

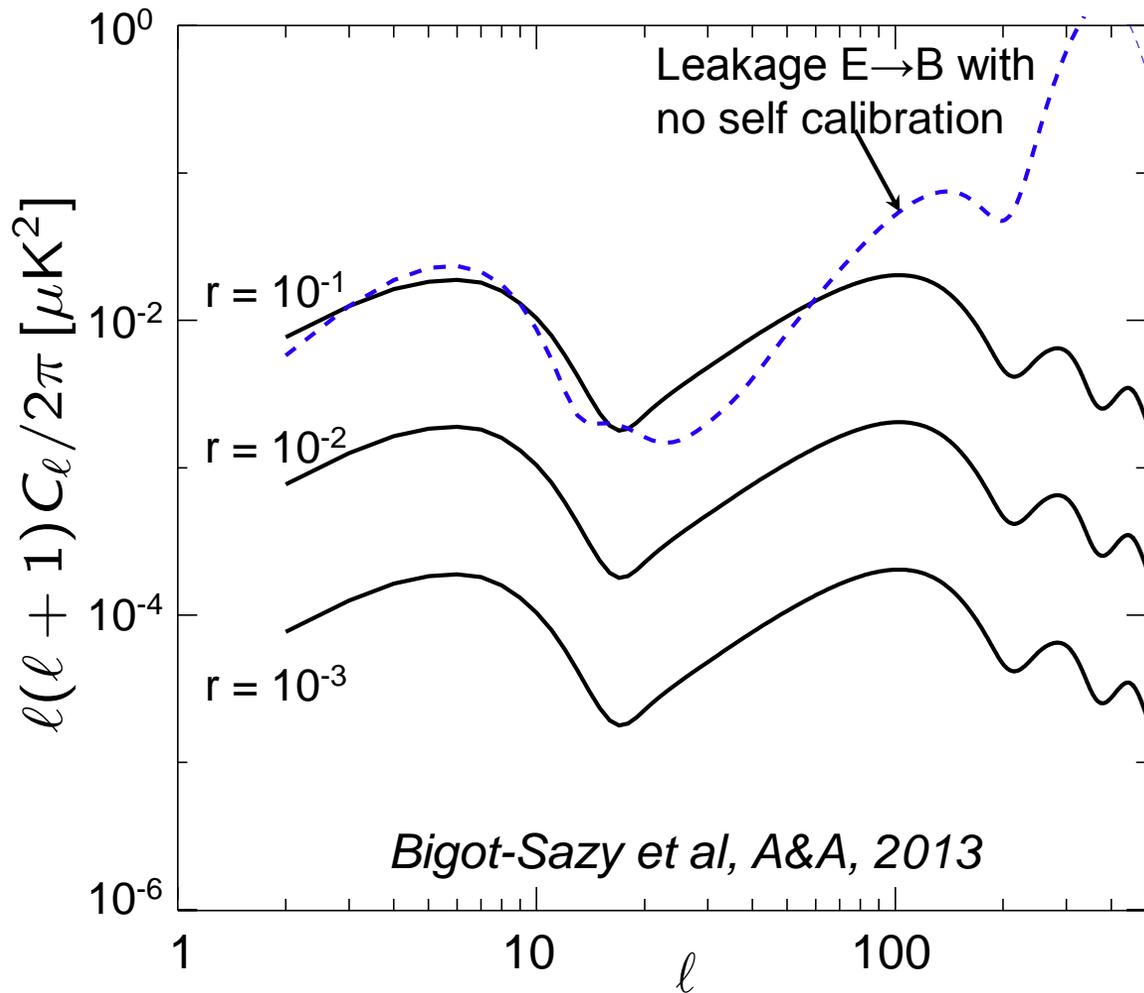
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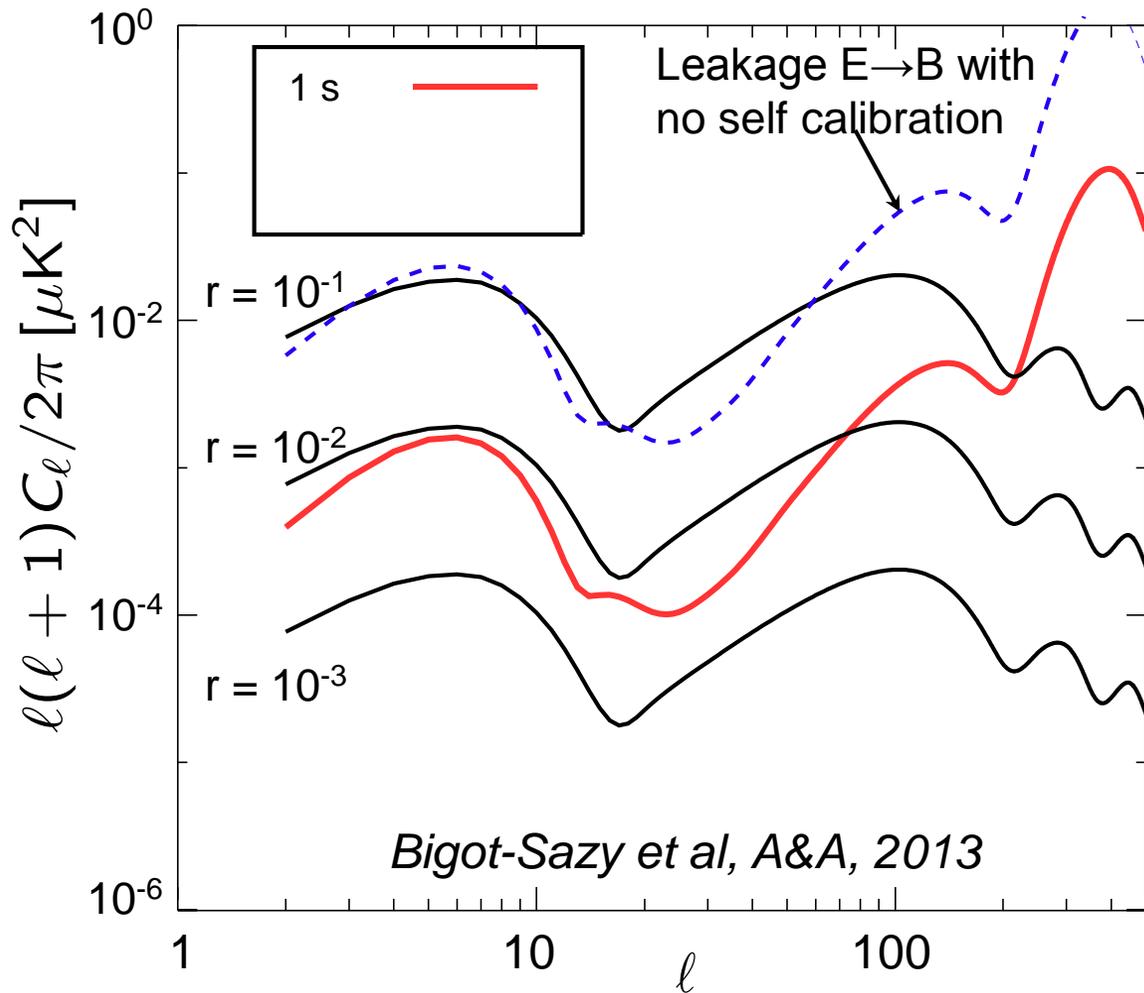
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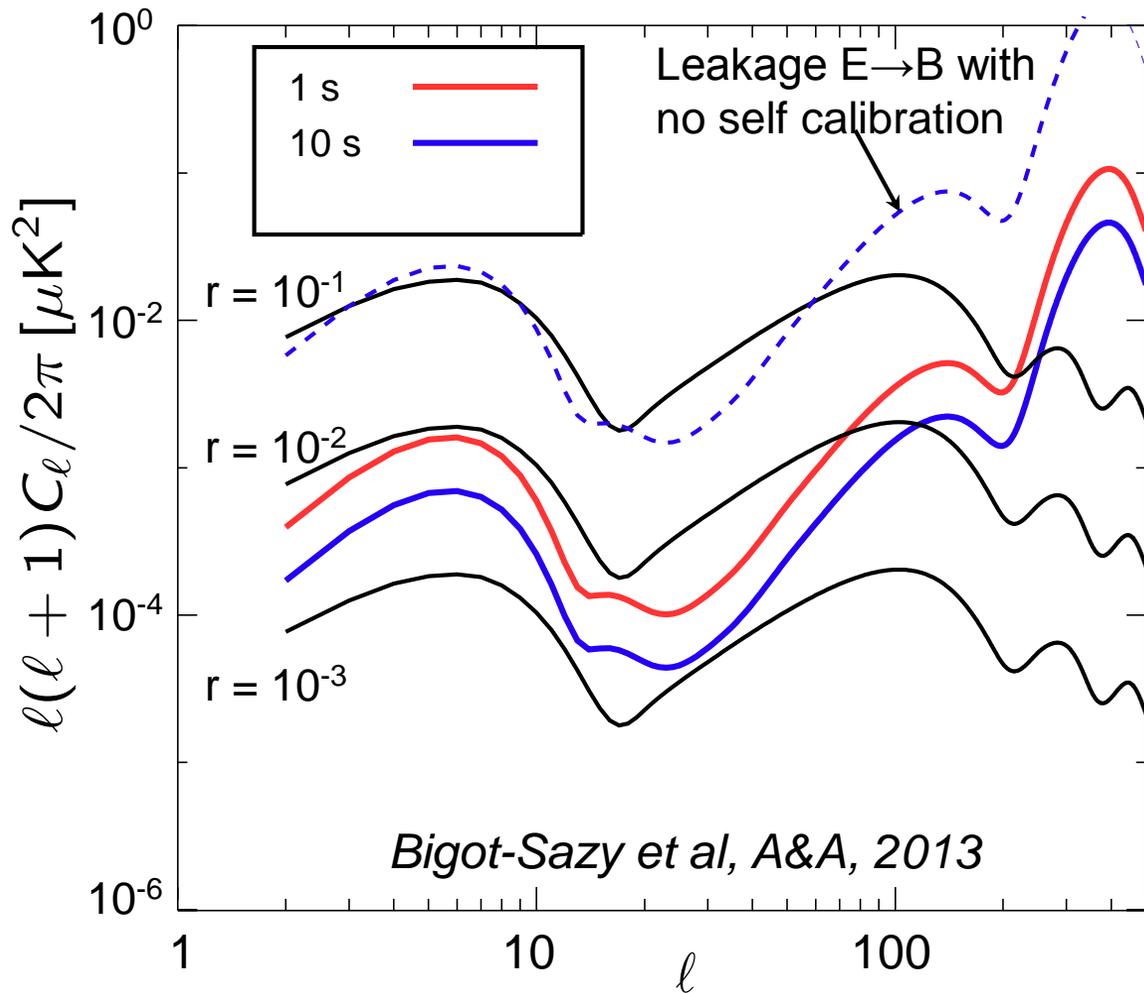
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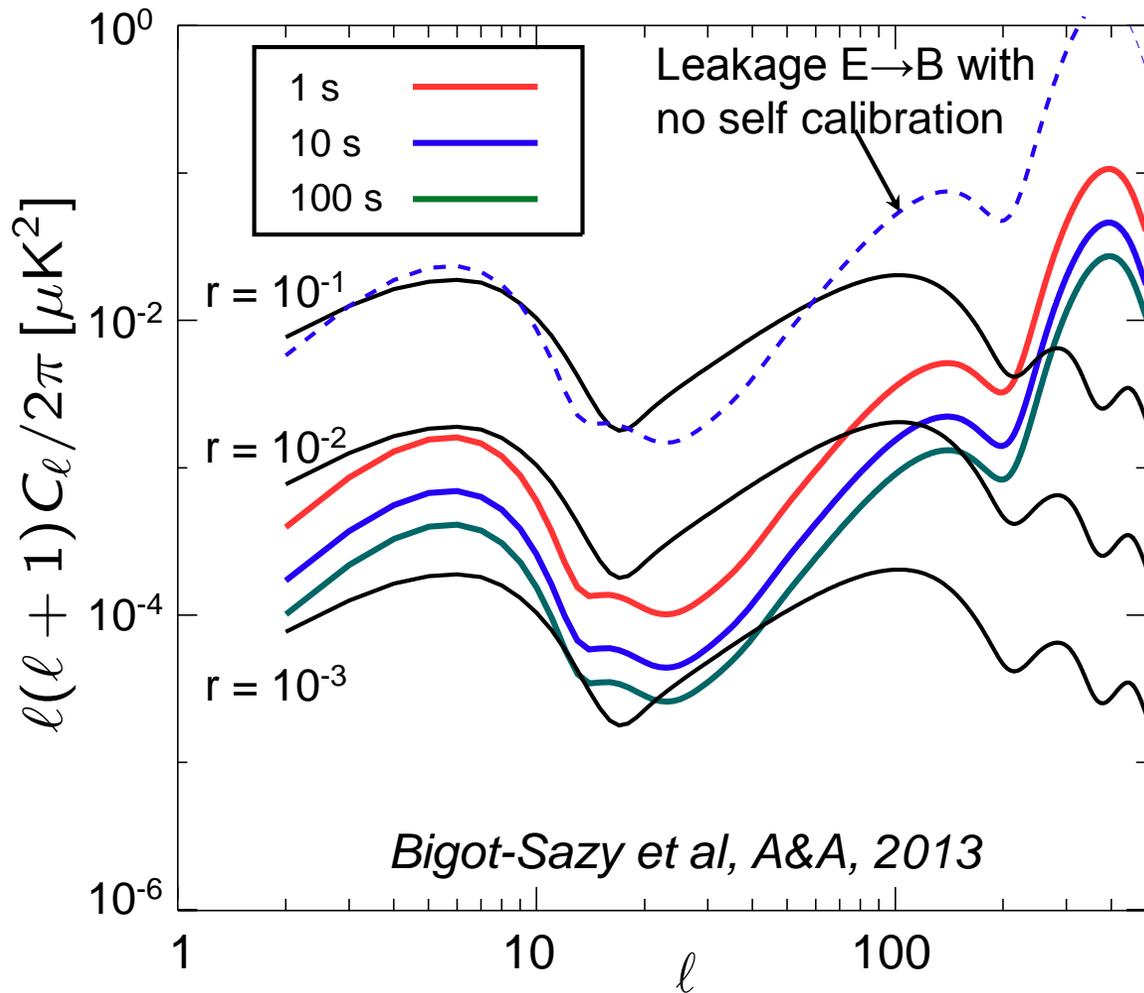
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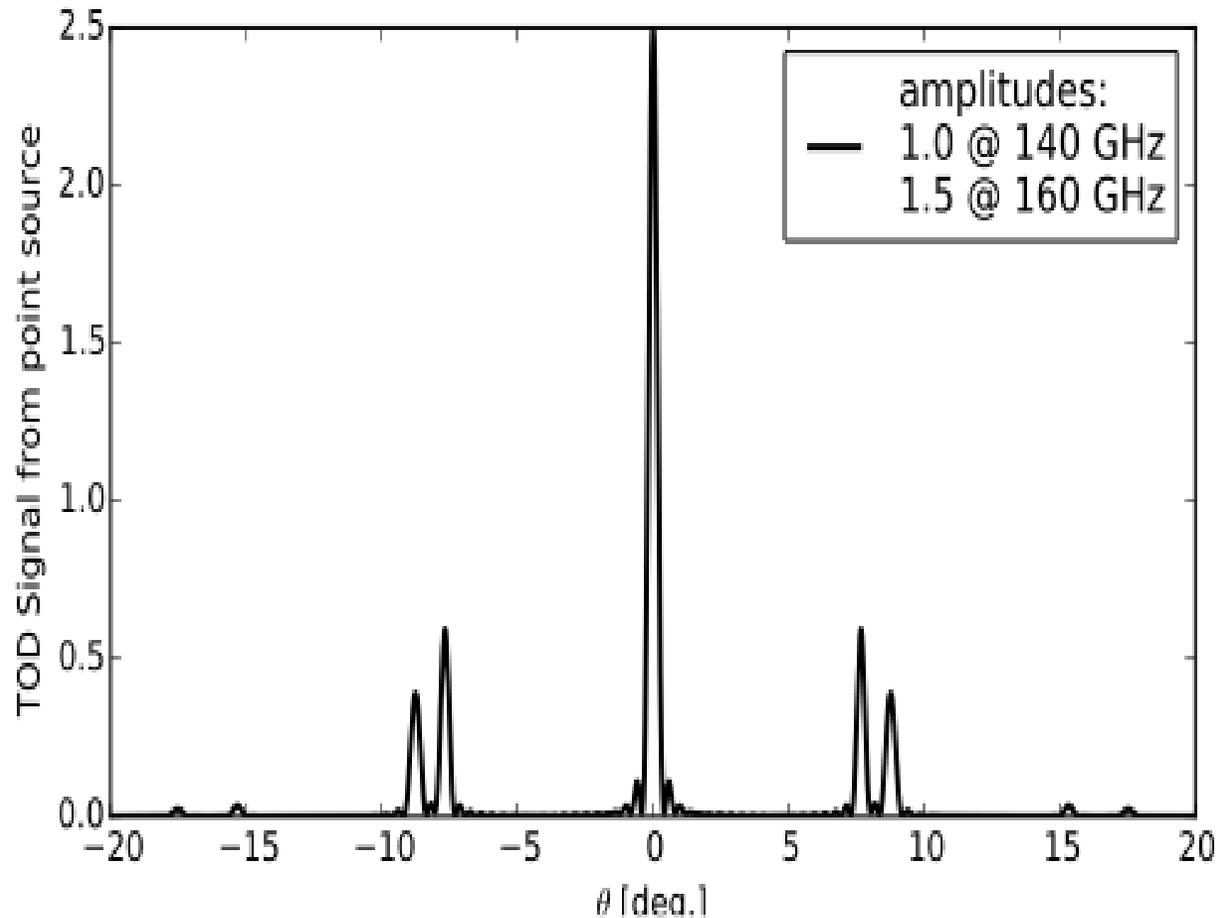
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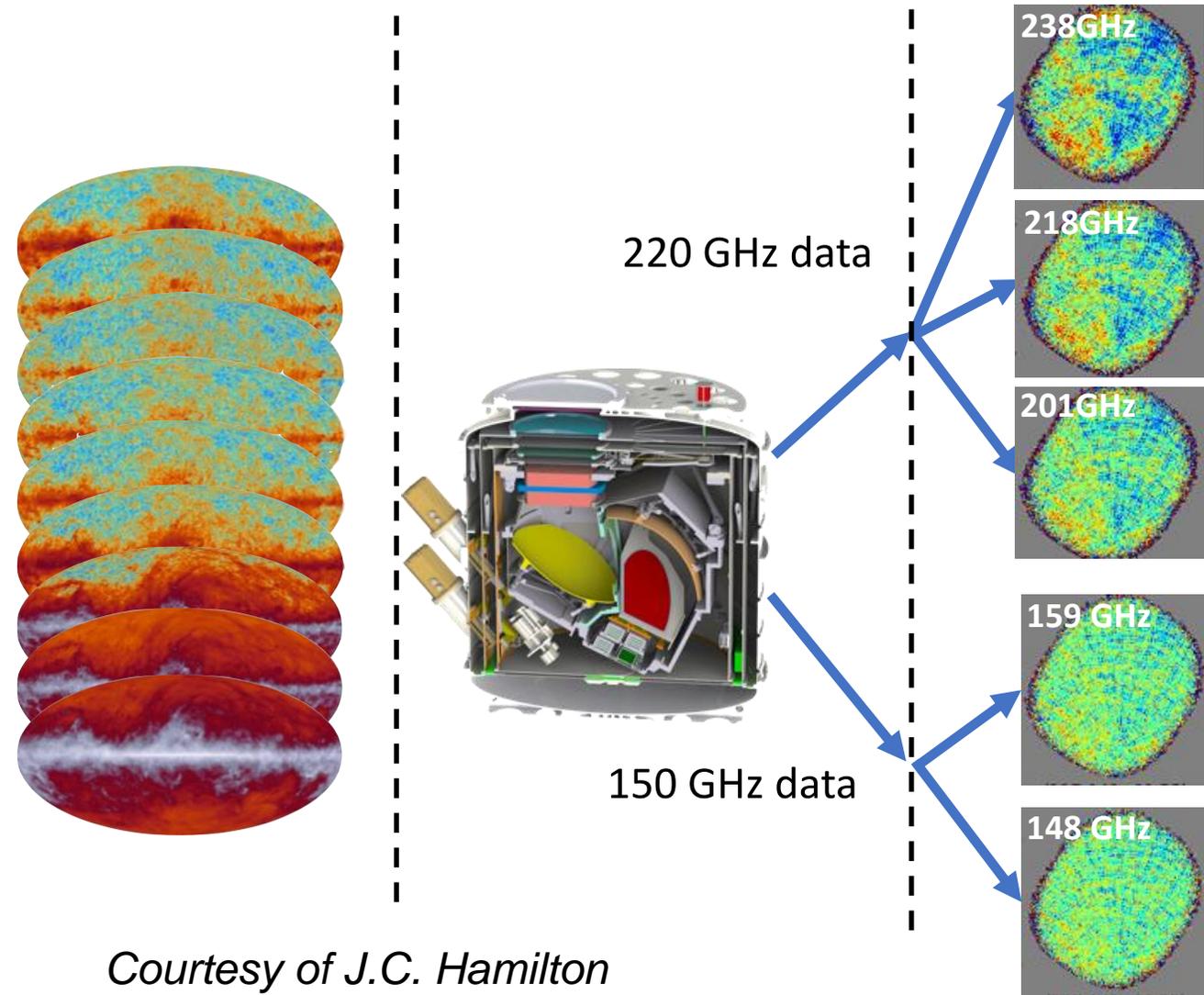
QUBIC in a nutshell – spectro-imaging



- The synthesized beam has depends on frequency (in the example the difference between two beams at 140 and 160 GHz)
- This means that it is possible to reconstruct the frequency information within each band
- Achievable spectral resolution about 5%

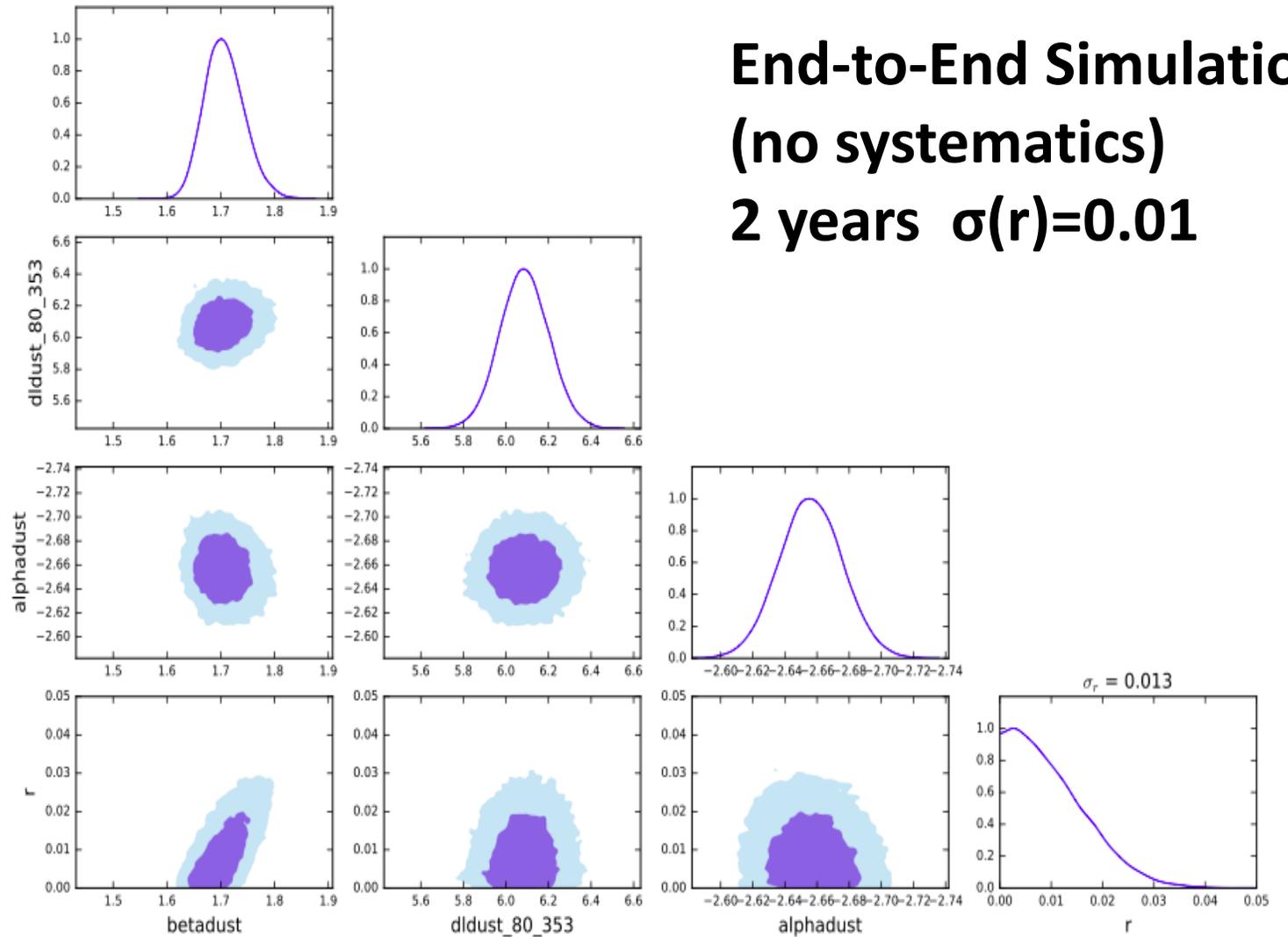
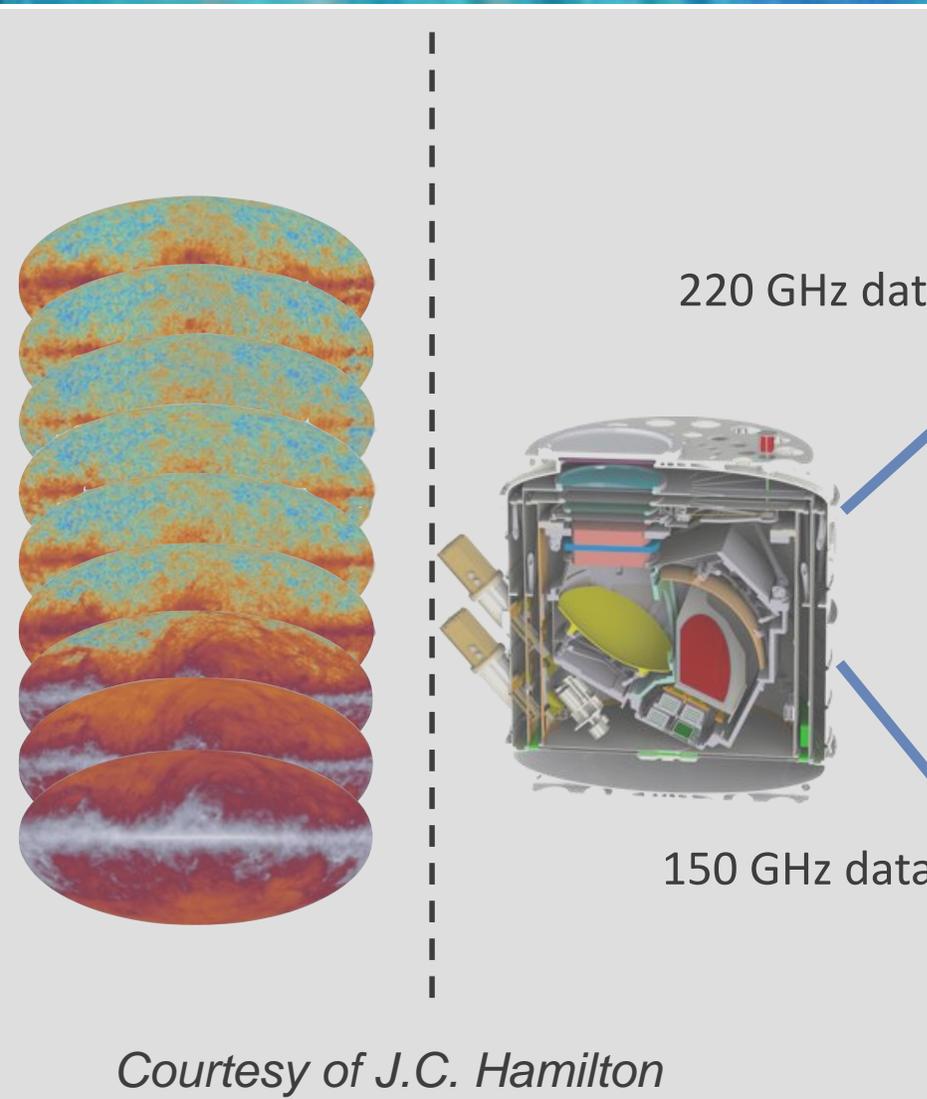
Courtesy of J.C. Hamilton

QUBIC in a nutshell – spectro-imaging



Courtesy of J.C. Hamilton

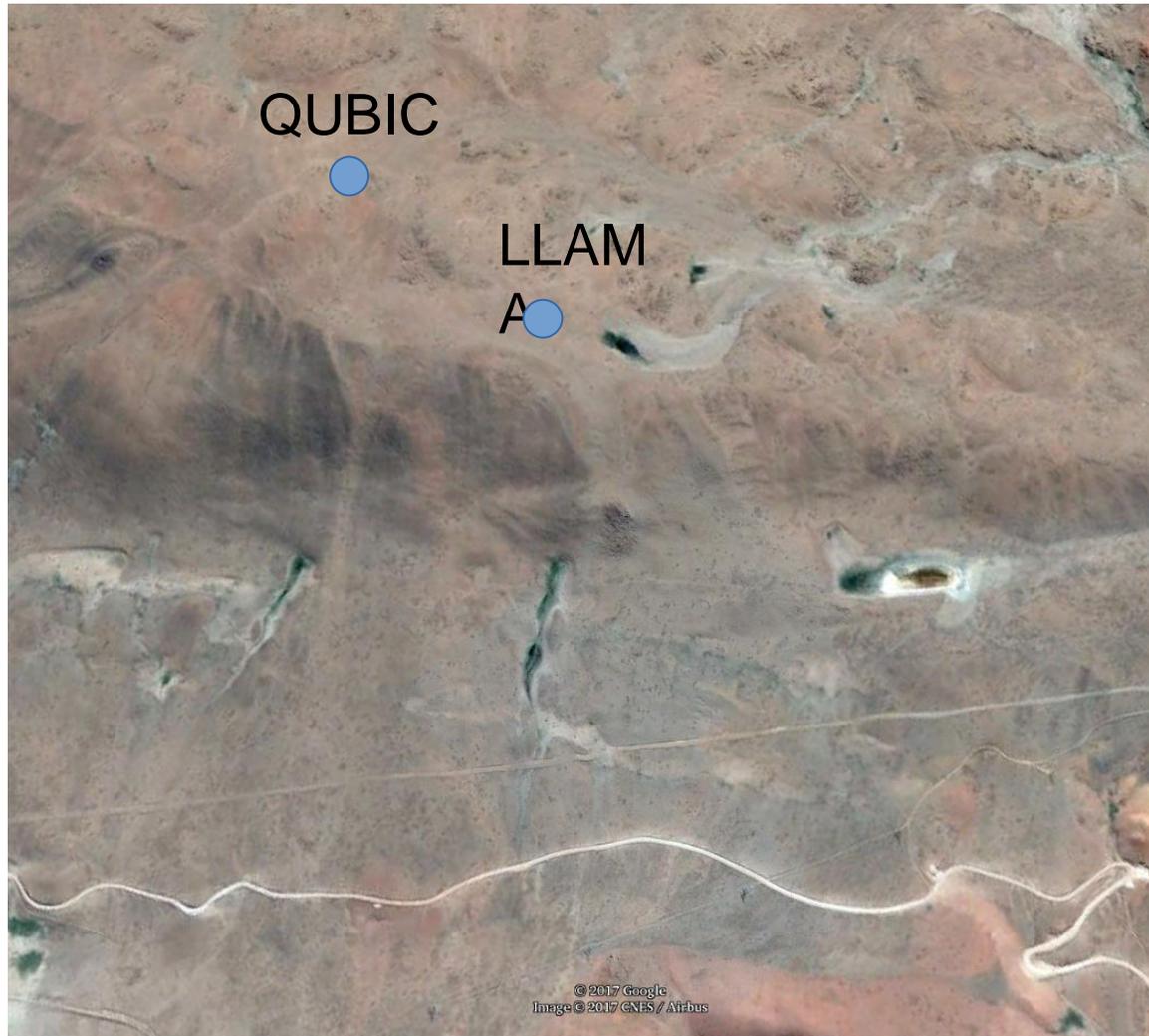
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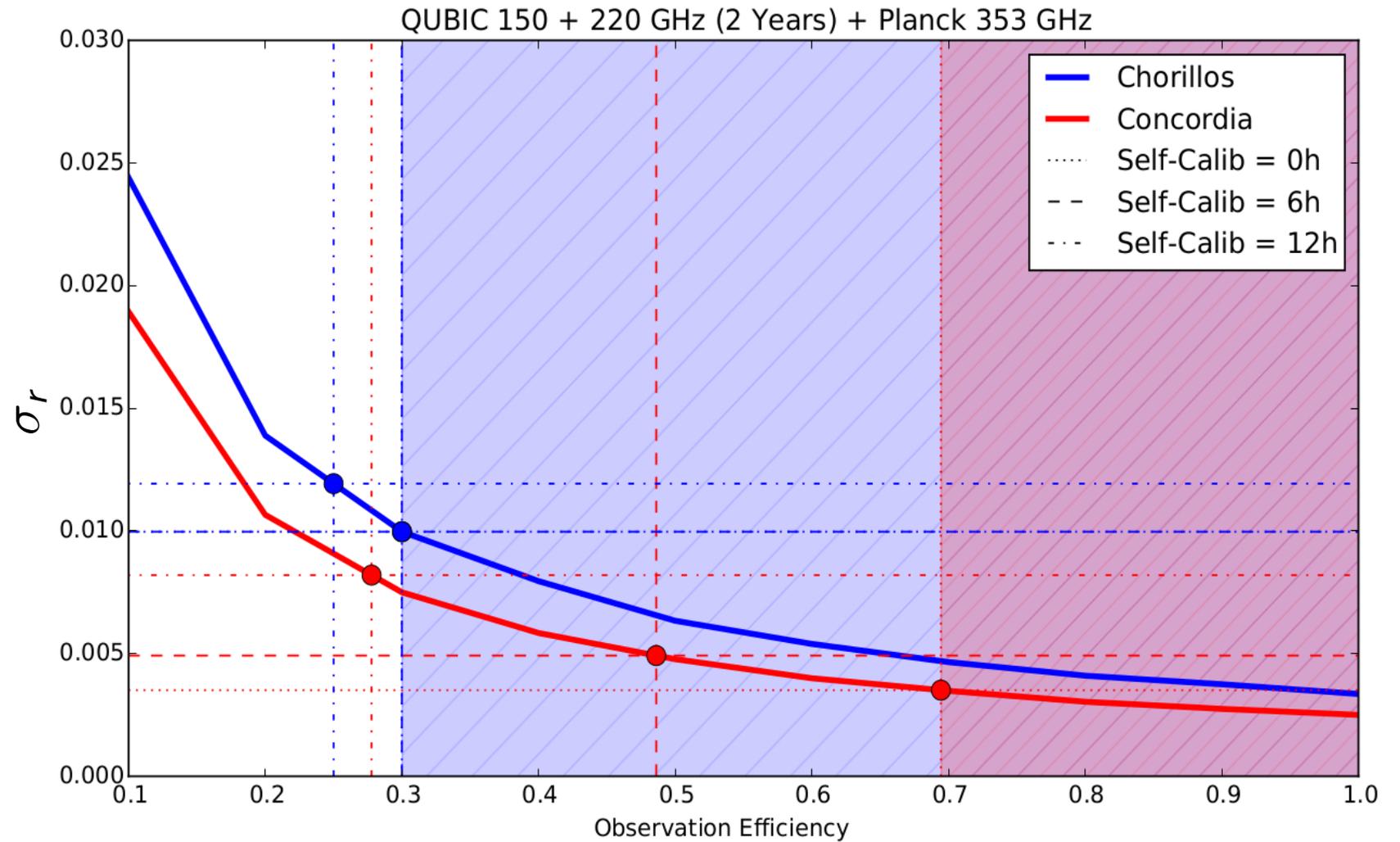
QUBIC site



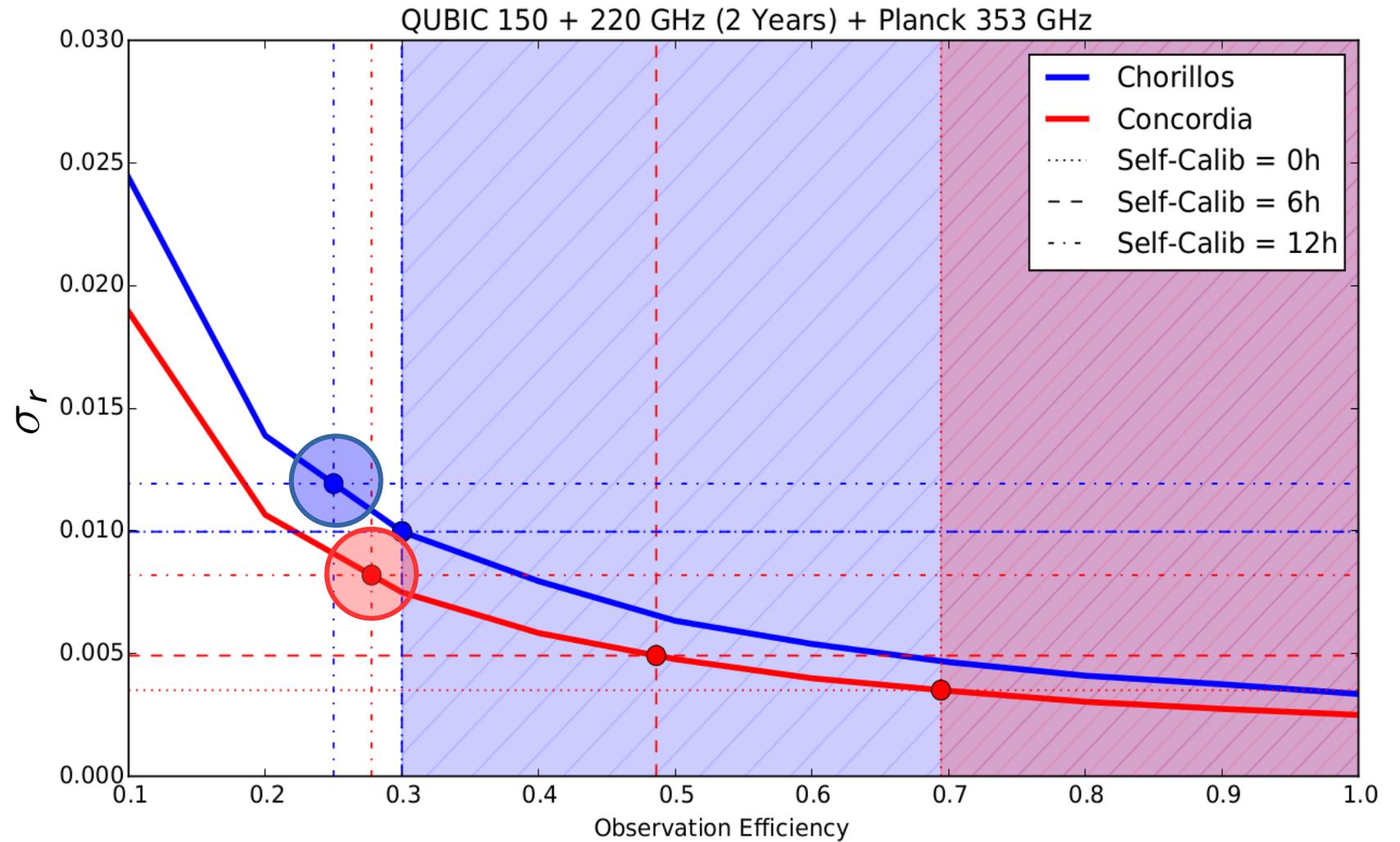
QUBIC site



QUBIC site quality

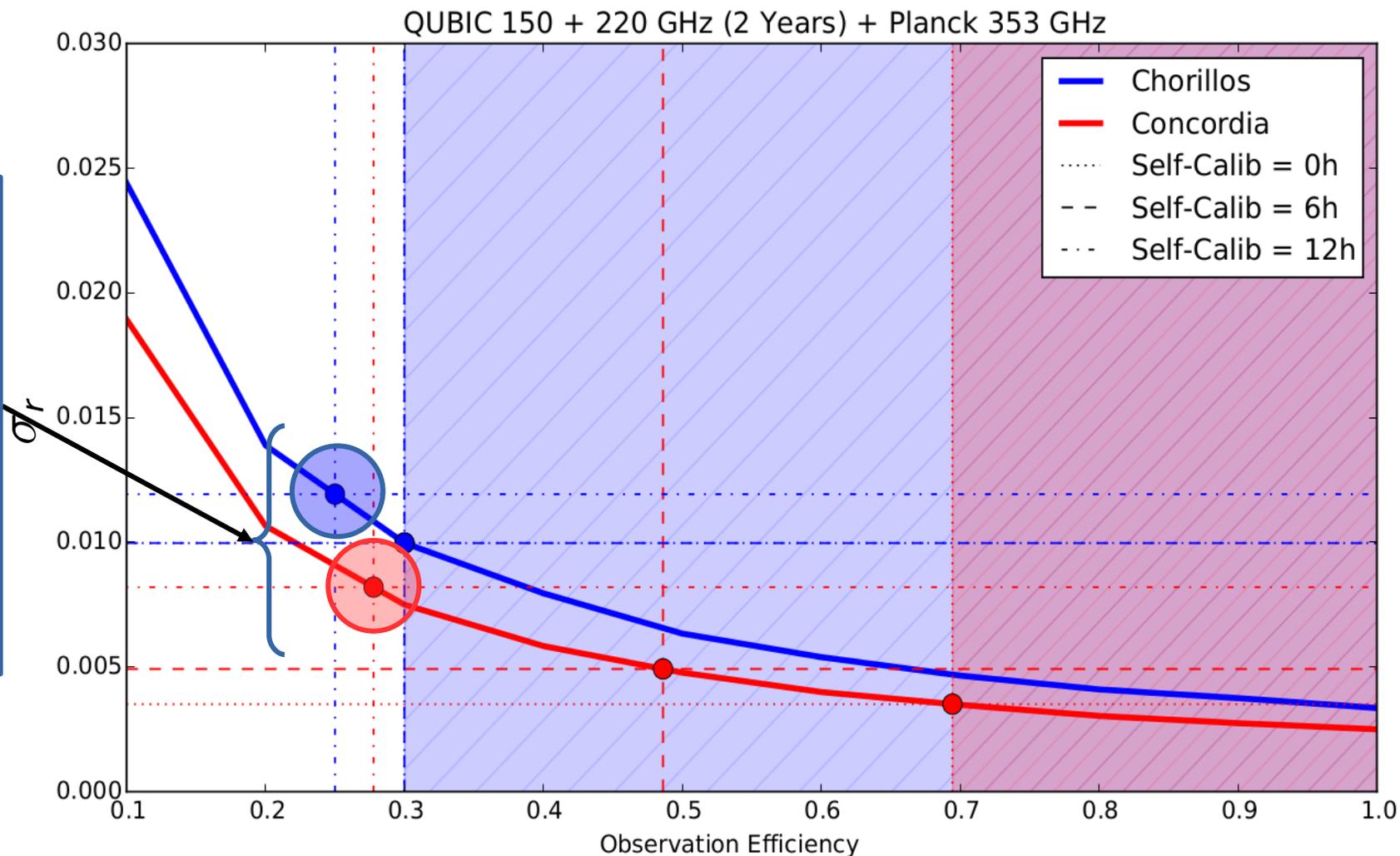


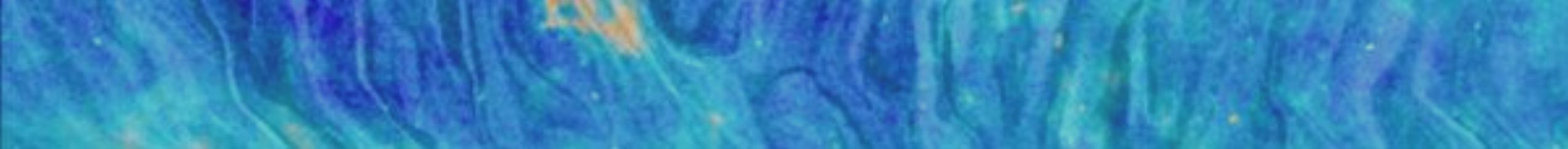
QUBIC site quality



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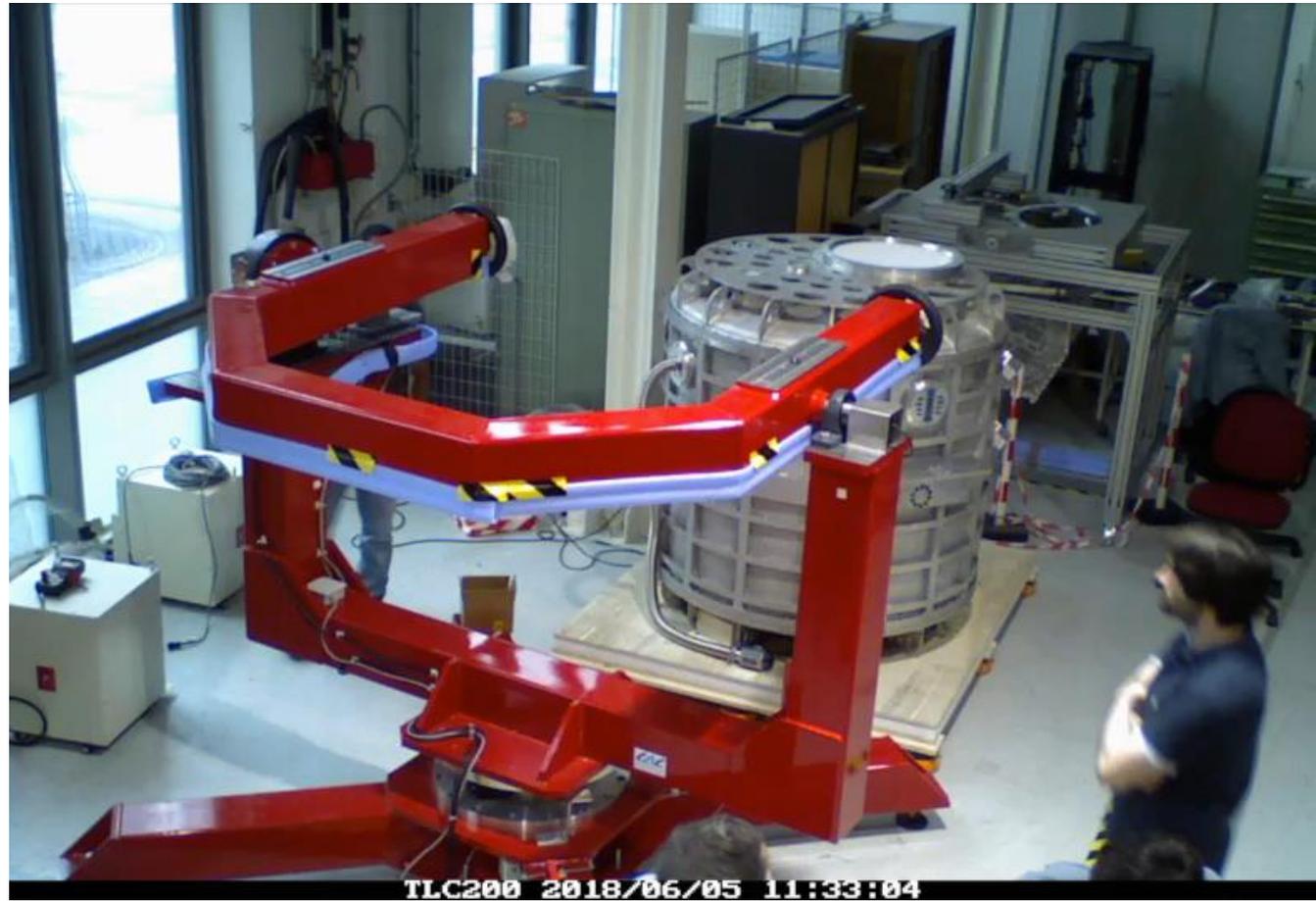
With 12-hours per day spent doing self calibration Argentinian site yields a factor ~ 1.4 reduction in sensitivity compared to Antactica





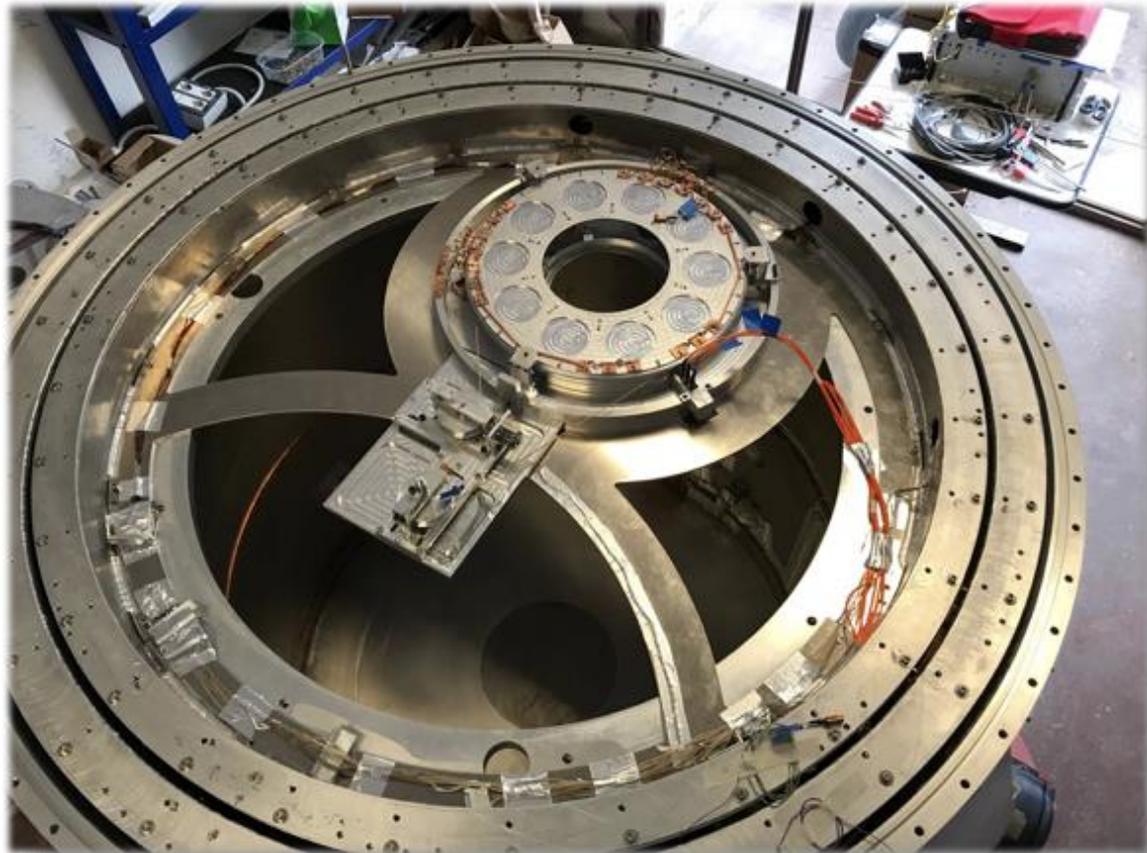
QUBIC cryostat at Rome La Sapienza

(courtesy G. D'Alessandro)



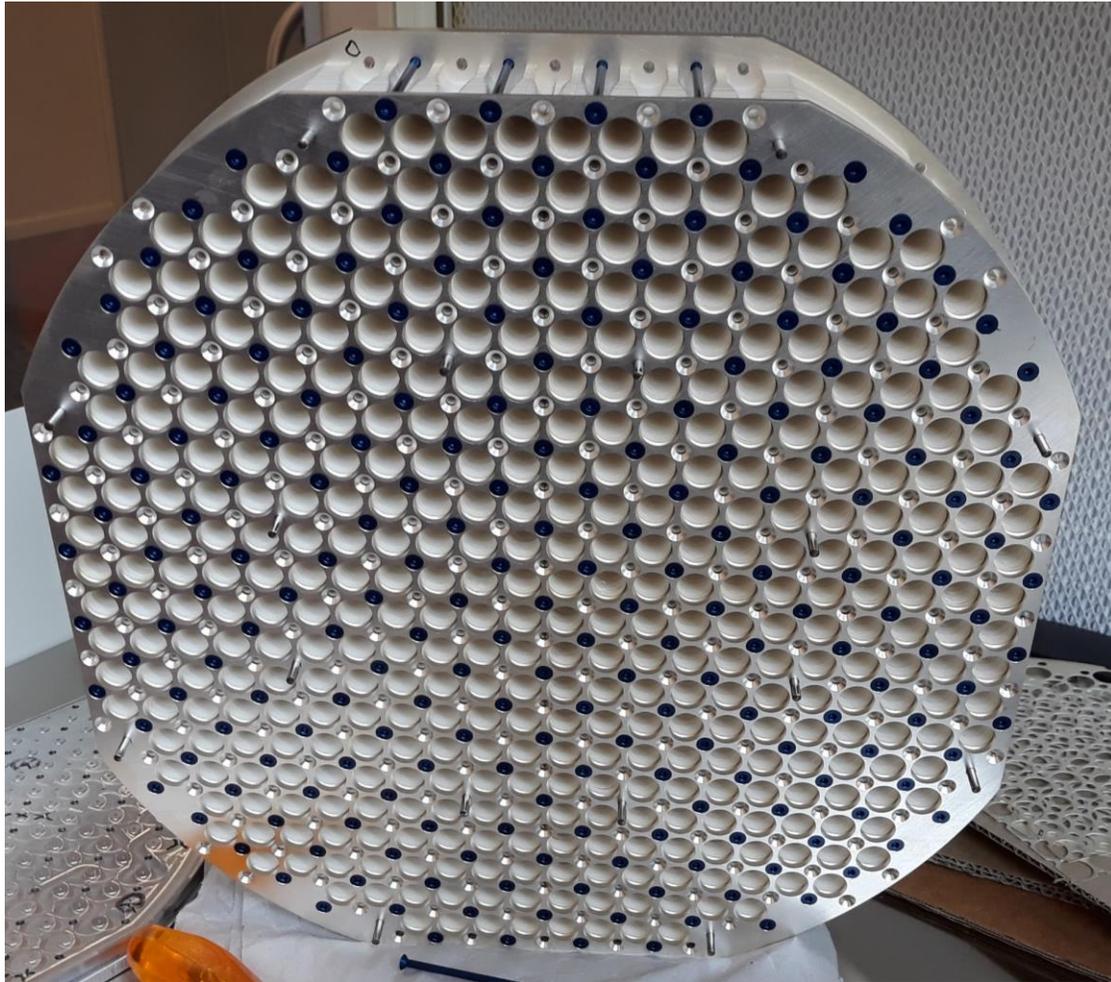
QUBIC HWP rotator at Rome La Sapienza

(courtesy G. D'Alessandro)



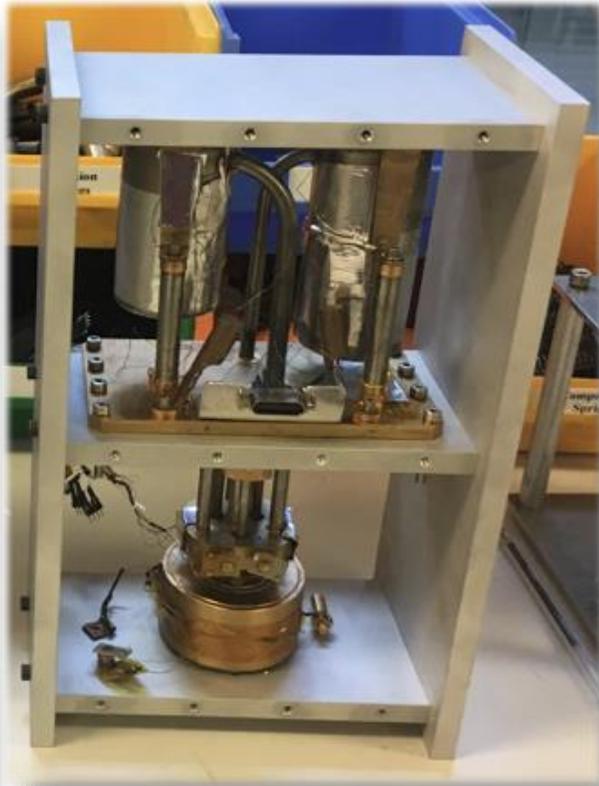
Feedhorn antennas at Milano Statale

(courtesy F. Cavaliere)



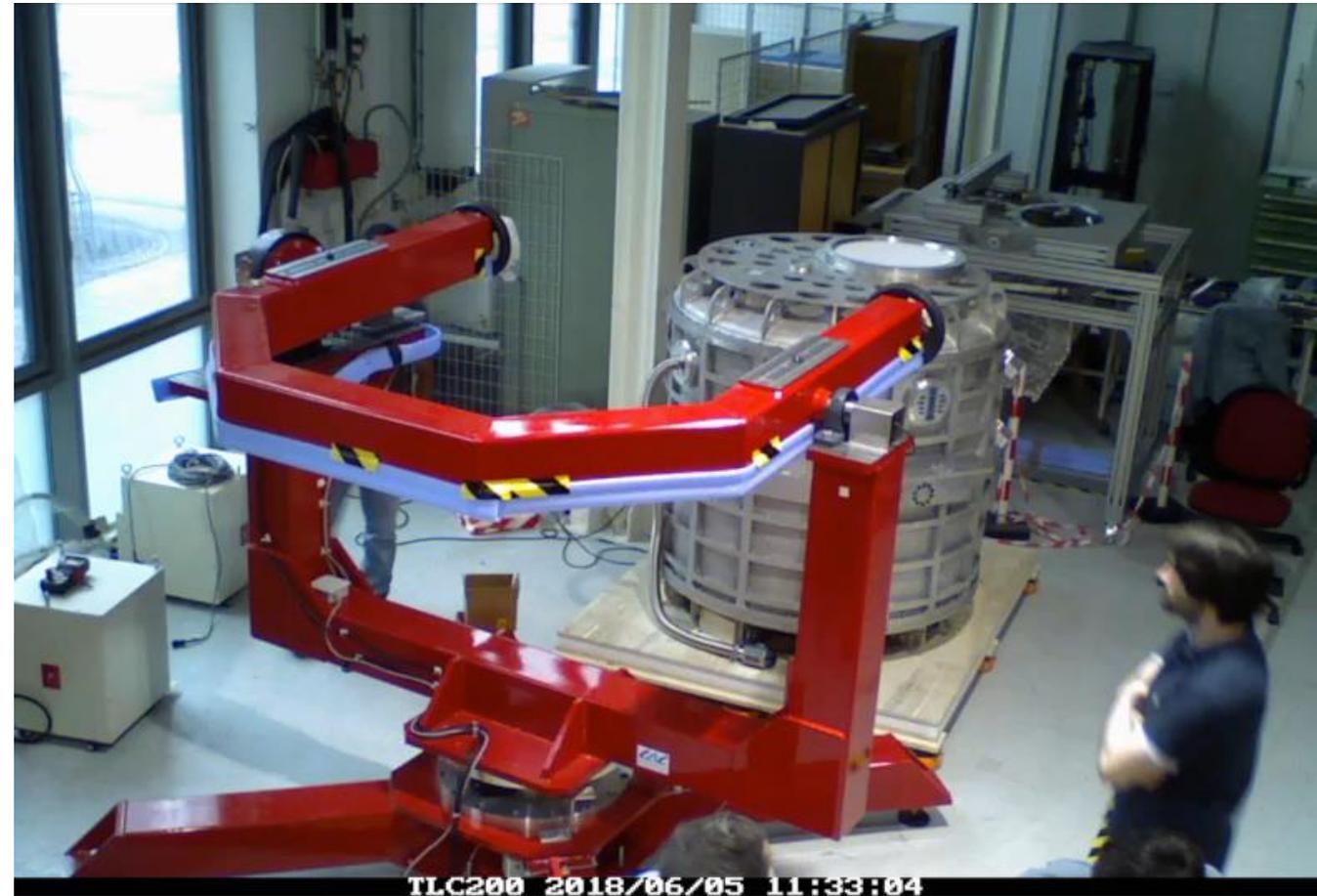
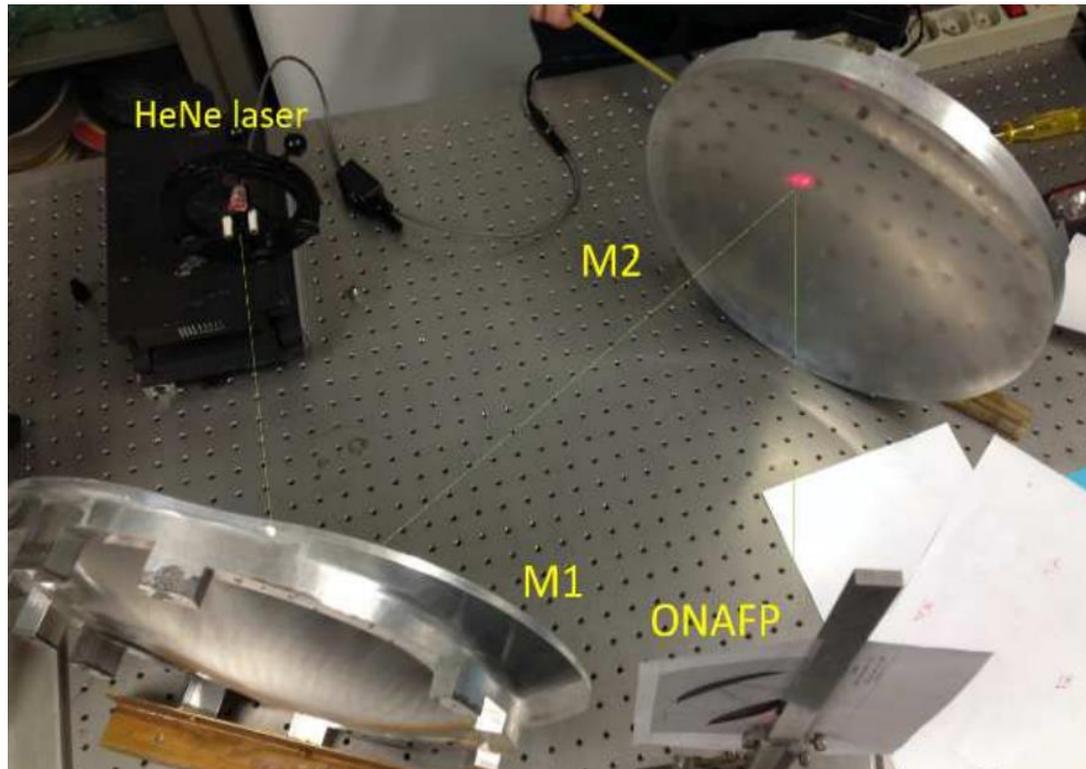
He4 fridge at Manchester

(courtesy A. May)



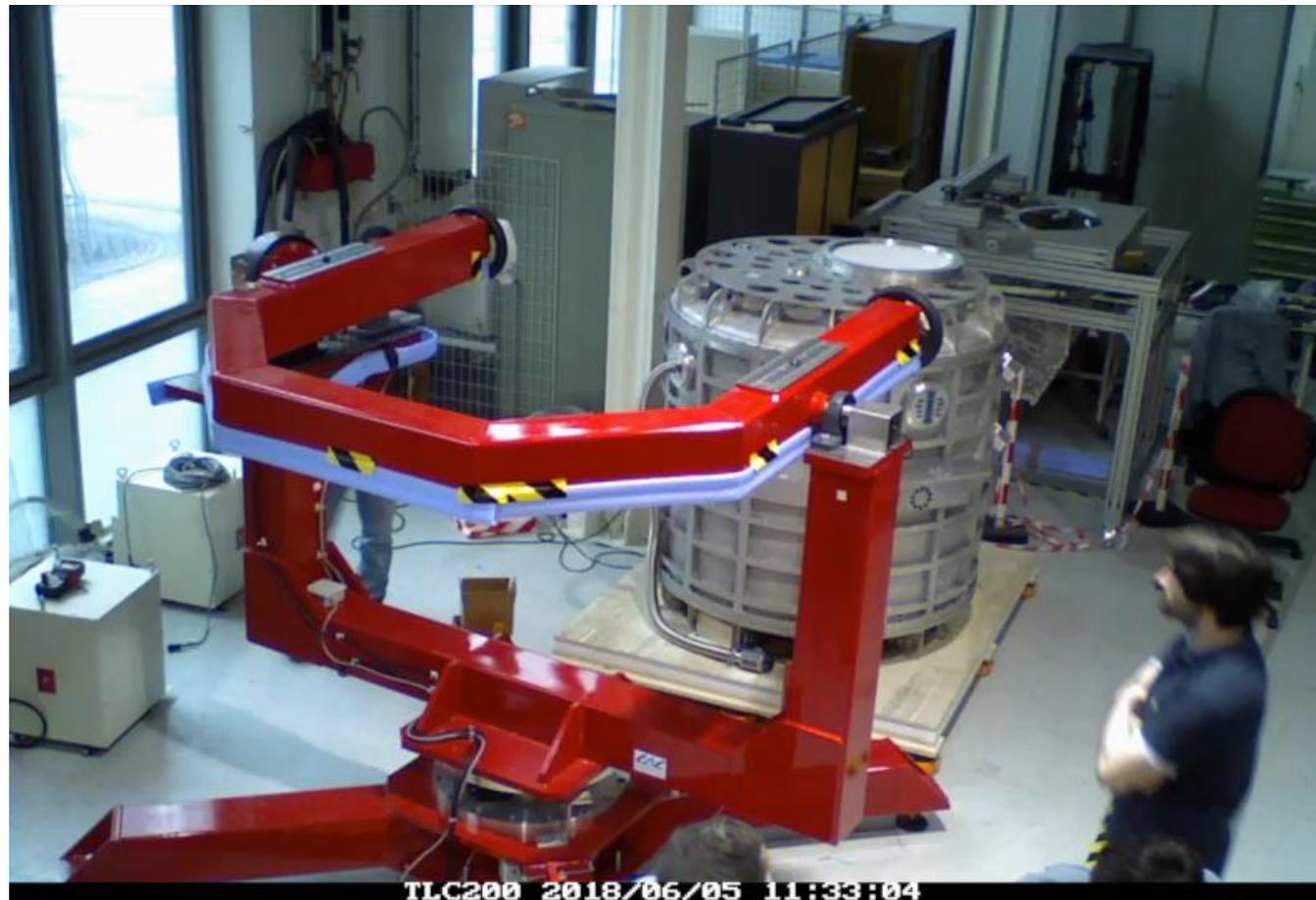
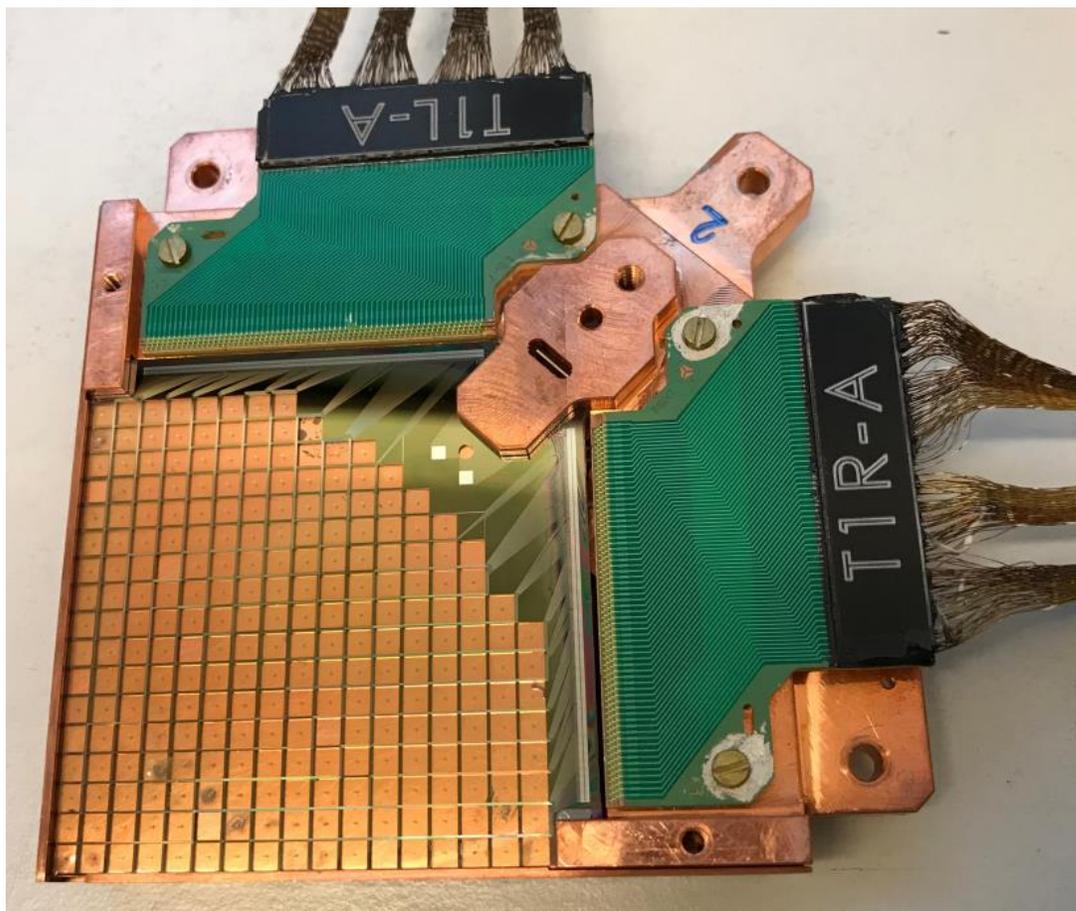
QUBIC mirrors alignment at Roma La Sapienza

(courtesy M. De Petris and M. Zannoni)



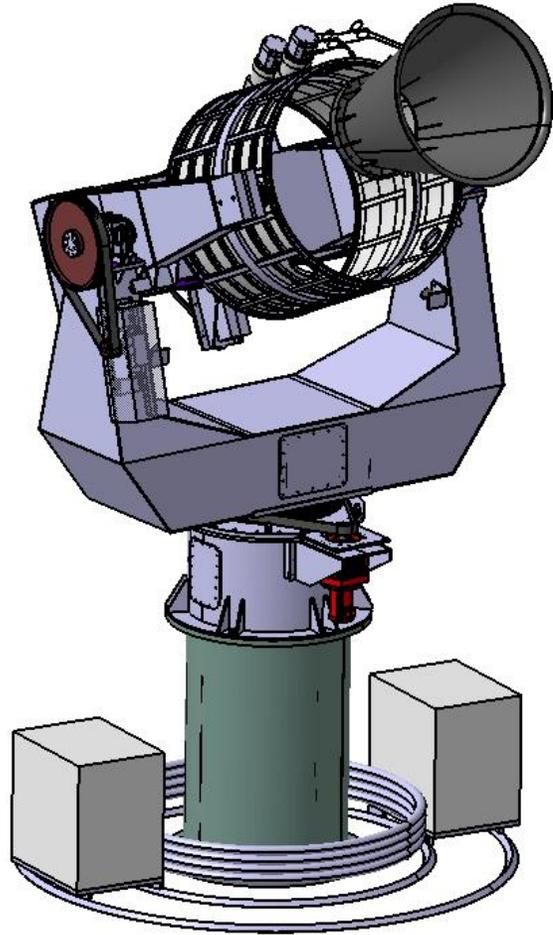
QUBIC detectors at APC

(courtesy S. Marnieros)



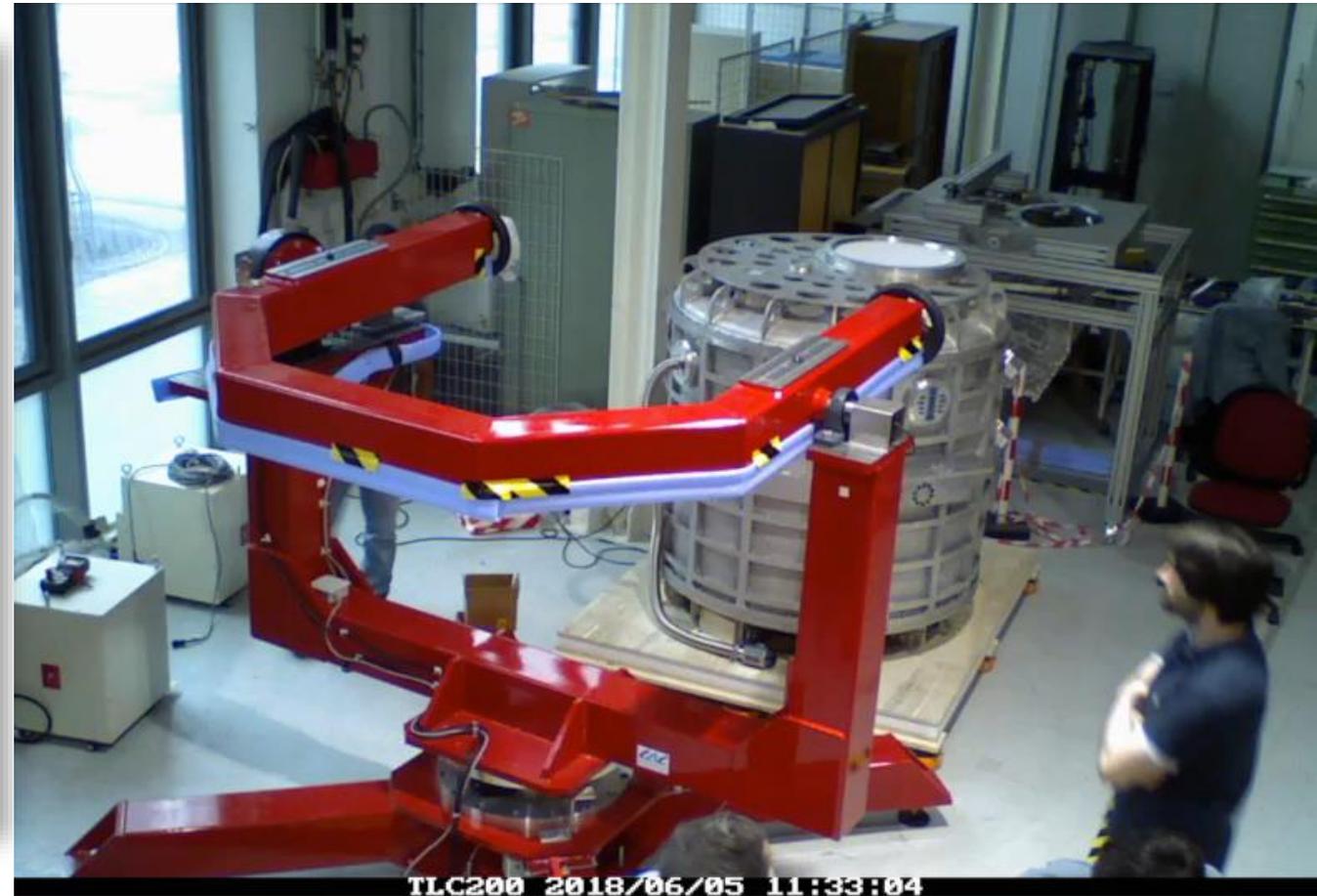
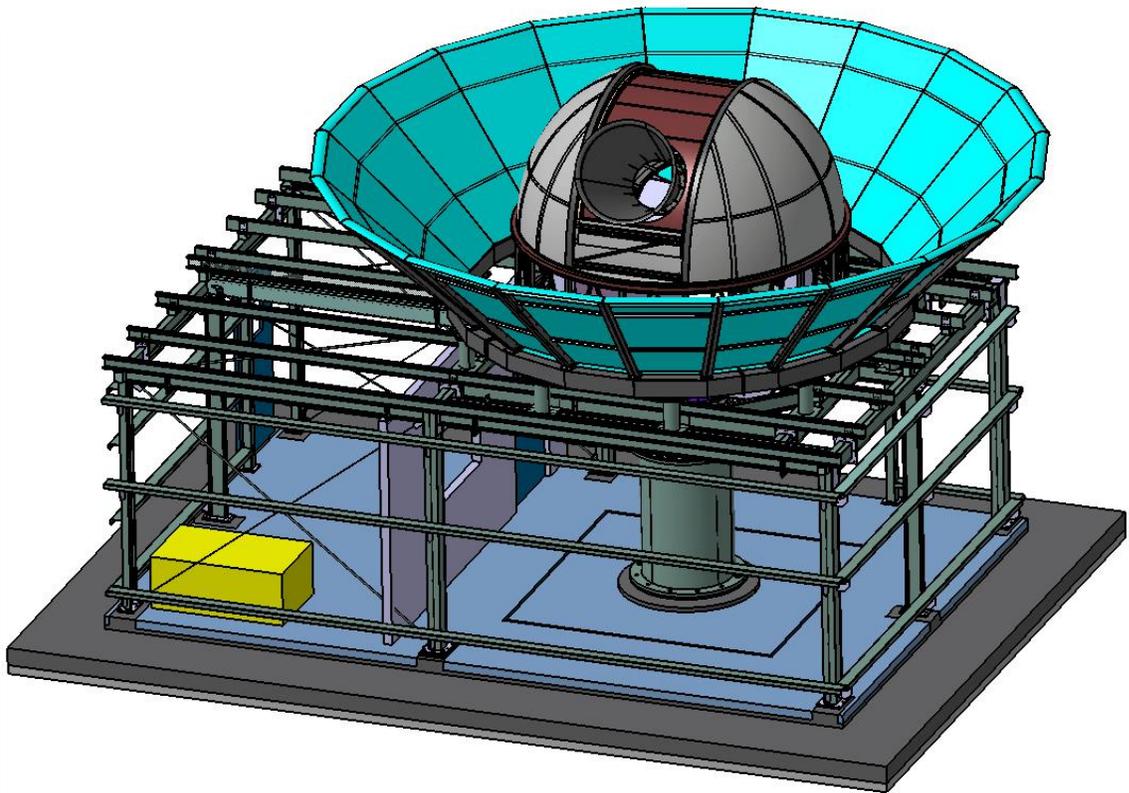
QUBIC mount development in Argentina

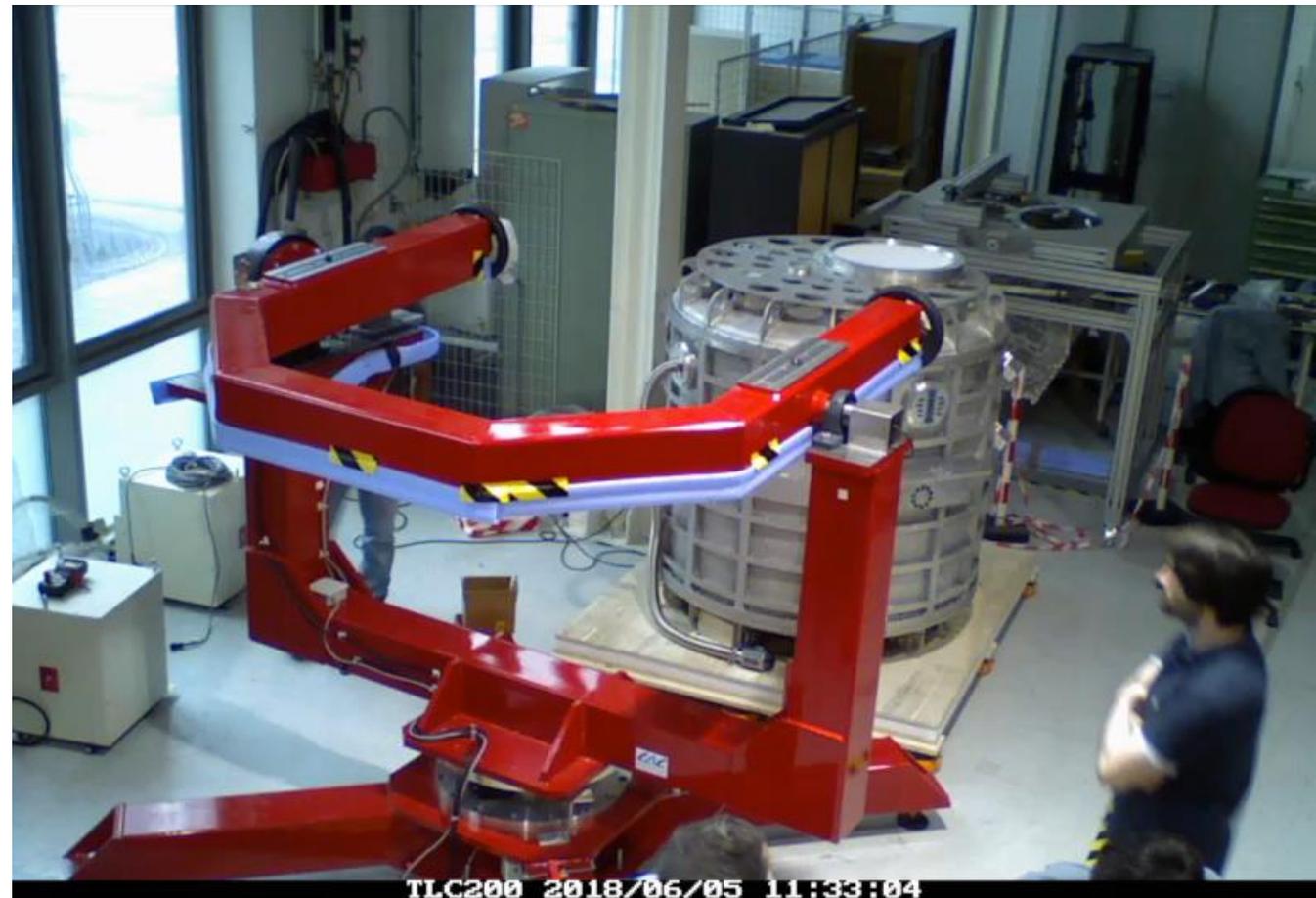
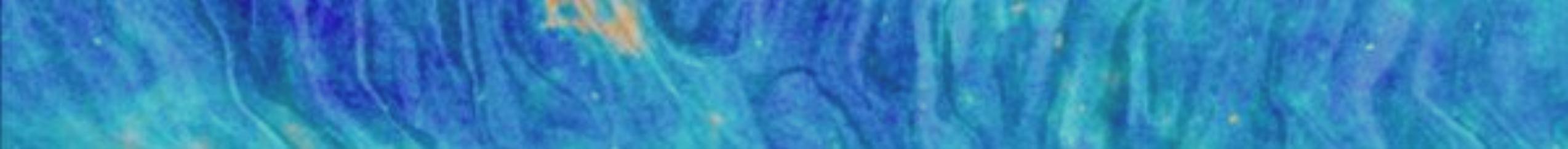
(courtesy P. Ringegni and M. Mundo)



QUBIC shelter development in Argentina

(courtesy R. Ringegni and M. Mundo)





Next steps

- Autumn 2018 – Technological demonstrator calibration in Paris
- First half of 2019 – shipment and installation of Technological demonstrator in Argentina, parallel development of Final Instrument components (detectors, mirrors, switches).
- Second half of 2019 – first light and data taking with Technological Demonstrator, shipment of Final Instrument parts and integration of Final Instrument in Salta
- Aim at first light with Final Instrument during 2019

Conclusions and perspectives

- CMB B-modes are a challenging quest. Measurements limited by systematic effects and foregrounds
- QUBIC responds with a challenging instrument with a design that is robust against instrumental effects.
- The TD will demonstrate the design, the first module will show the scientific potential
- Long-term plans foresee exploitation of the Argentinean site with deployment several modules with a wide frequency coverage

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
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 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 Geofísicas, Argentina
 Centro Atómico Bariloche and Istituto Balseiro, Argentina
 Instituto de Tecnologías en Detección y Astroparticulas, Argentina
 Instituto Argentino de Radioastronomía, Argentina



Funding

A collection of logos for funding agencies. The logos include:

- CNRS IN2P3 Les deux Infinis
- CNRS INSU observer et comprendre
- ACAV
- ile de France
- ANR (Agence Nationale de la Recherche)
- UnivEarthS (Laboratoire)
- CNEA (Comisión Nacional de Energía Atómica)
- Ministerio de Ciencia, Tecnología e Innovación Productiva, Presidencia de la Nación
- CONICET (Consejo Nacional de Investigaciones Científicas)
- GOBIERNO DE LA PROVINCIA DE SALTA
- INFN (Istituto Nazionale di Fisica Nucleare)
- PROGRAMMA NAZIONALE DI RICERCHE IN ANTARTIDE
- SORBONNE PARIS CITE

