Exploring the primordial Universe with QUBIC,
The Q&U Bolometric Interferometer for Cosmology

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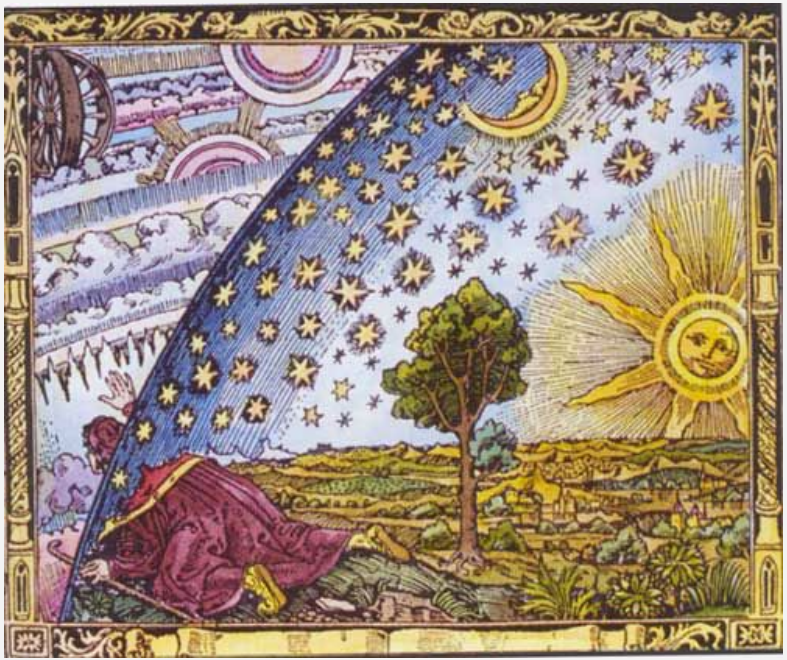
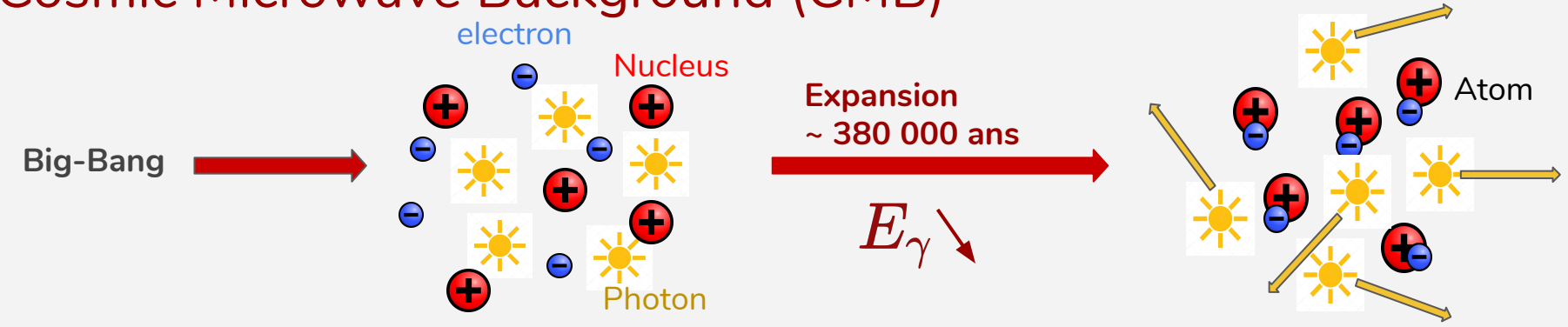
Supervisors : Jean-Christophe Hamilton
Steve Torchinsky

Rencontres des Jeunes Physicien.ne.s
November 29th, 2019

I. Cosmology: CMB and Inflation



Cosmic Microwave Background (CMB)



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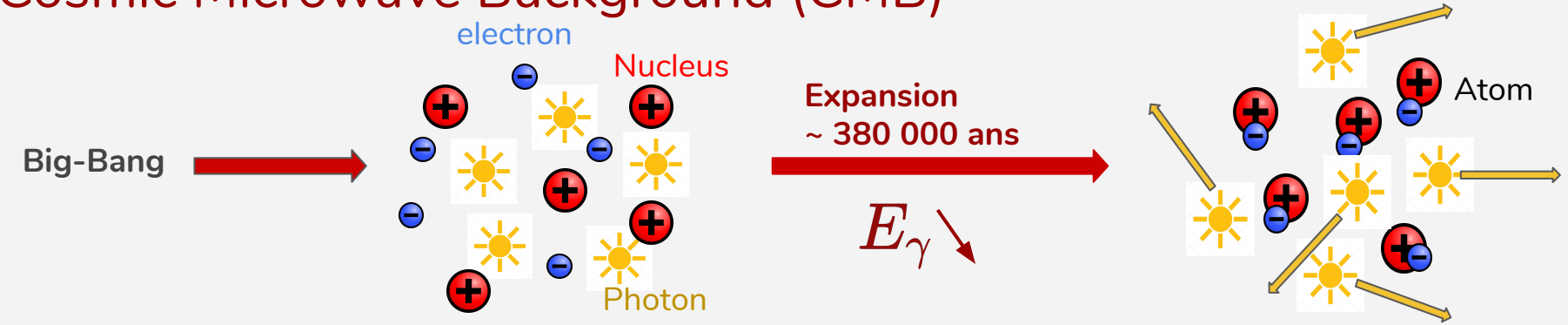
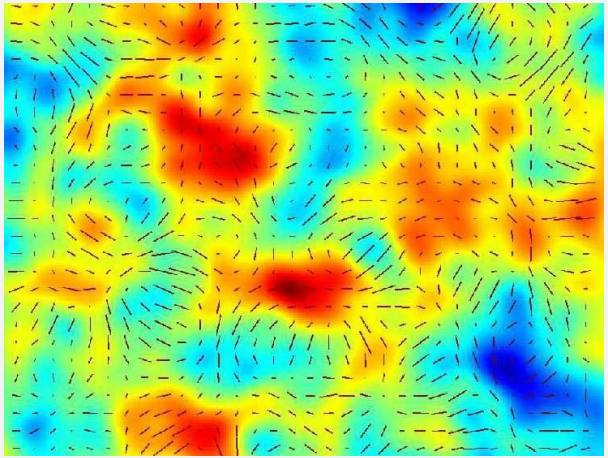


The CMB polarization: Stokes parameters

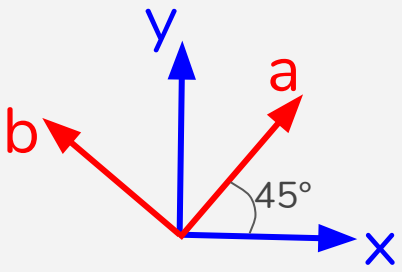


For each position on the sky :

$$I = E_x^2 + E_y^2$$

$$Q = E_x^2 - E_y^2$$

$$U = E_a^2 - E_b^2$$



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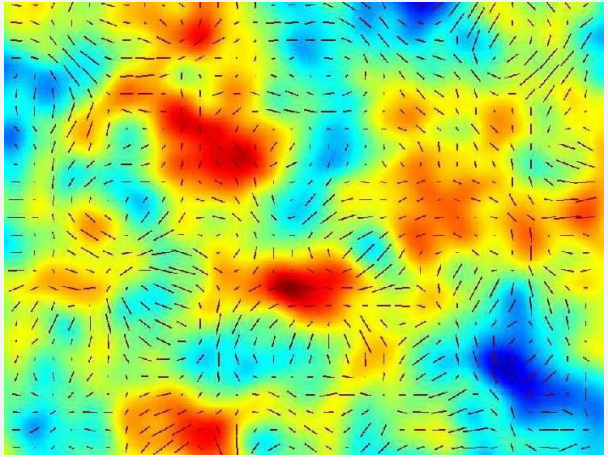

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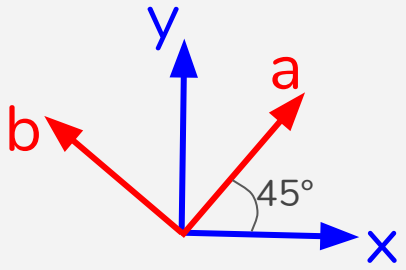


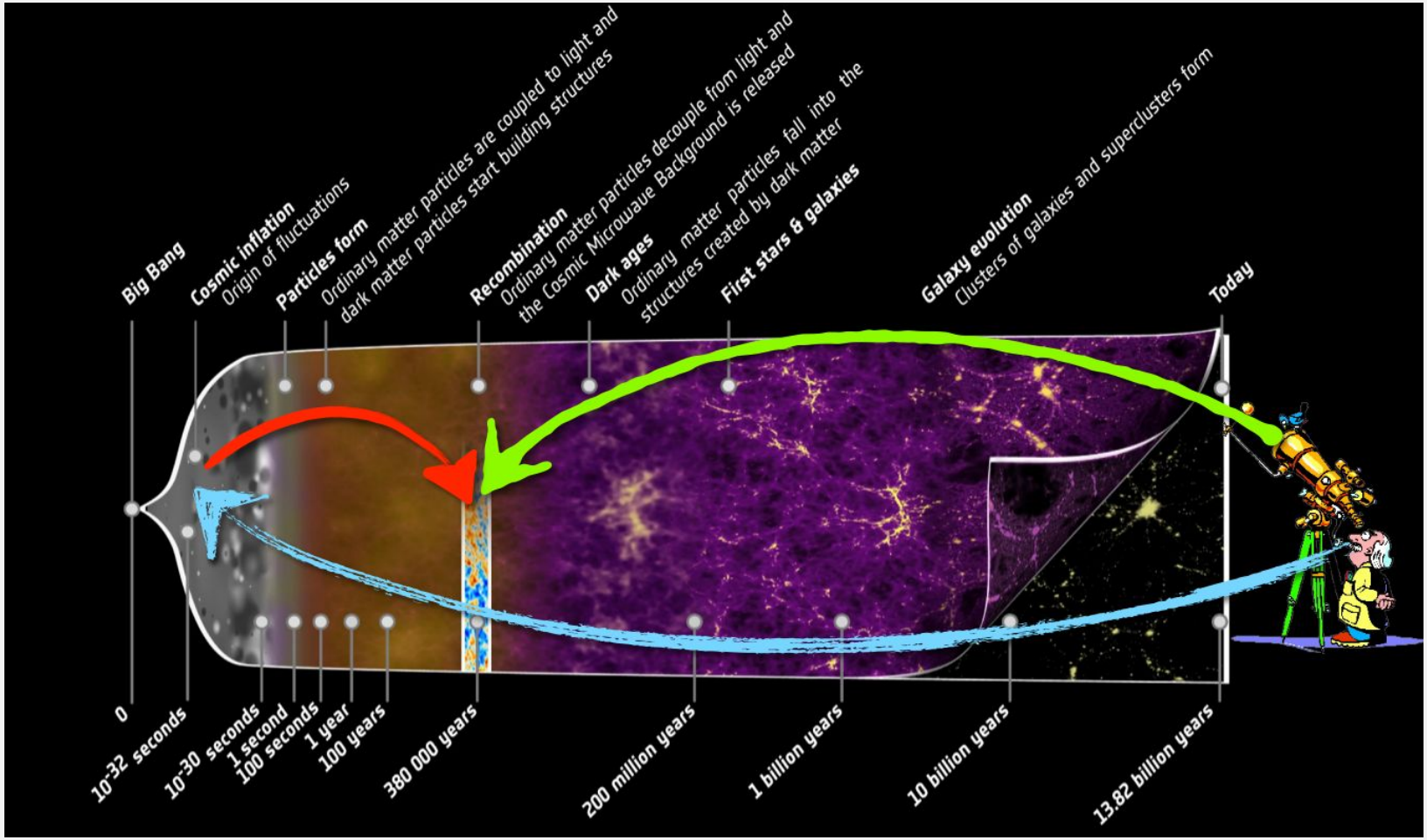
Problem : I, Q, U are defined with respect to the frame of your instrument

⇒ Using Q and U, one can build 2 scalar quantities with a global definition over the sky:

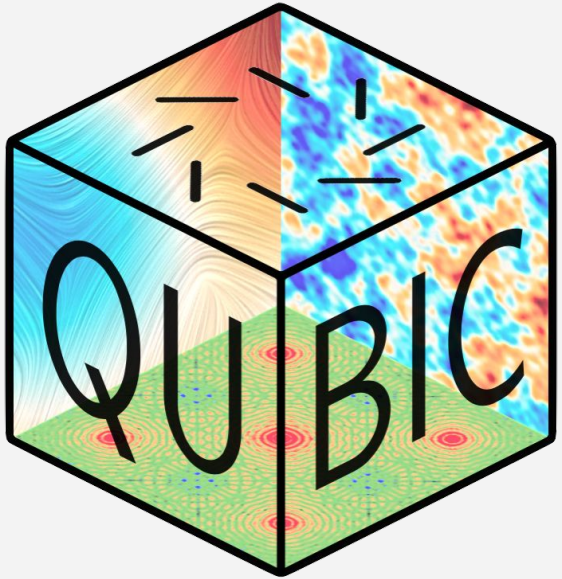
E modes

B modes

A clue for inflation



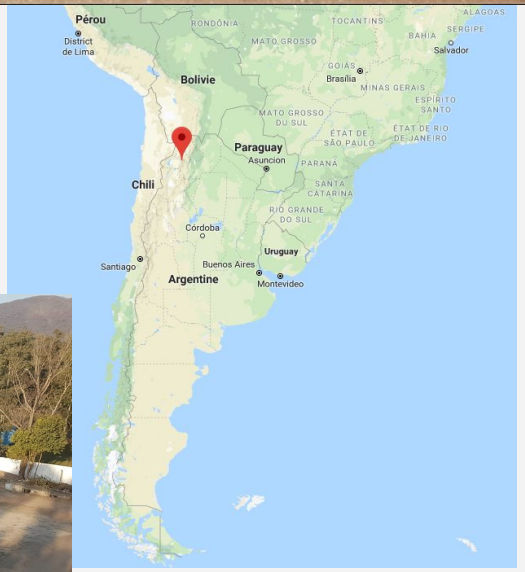
II. The QUBIC project



Calibration at APC

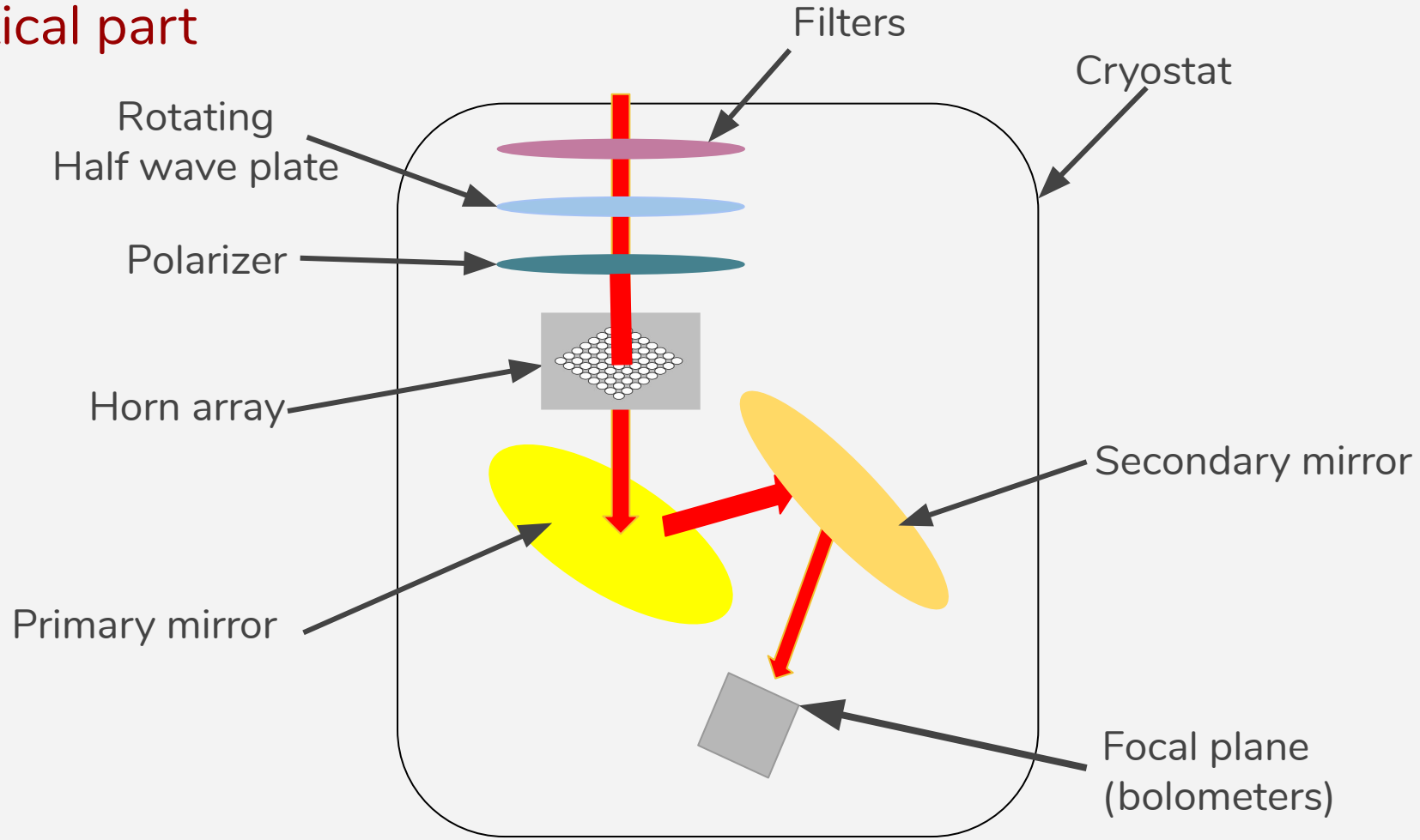
Observation site: Puna (~5000m)

Cryostat arrival
(May 2018)

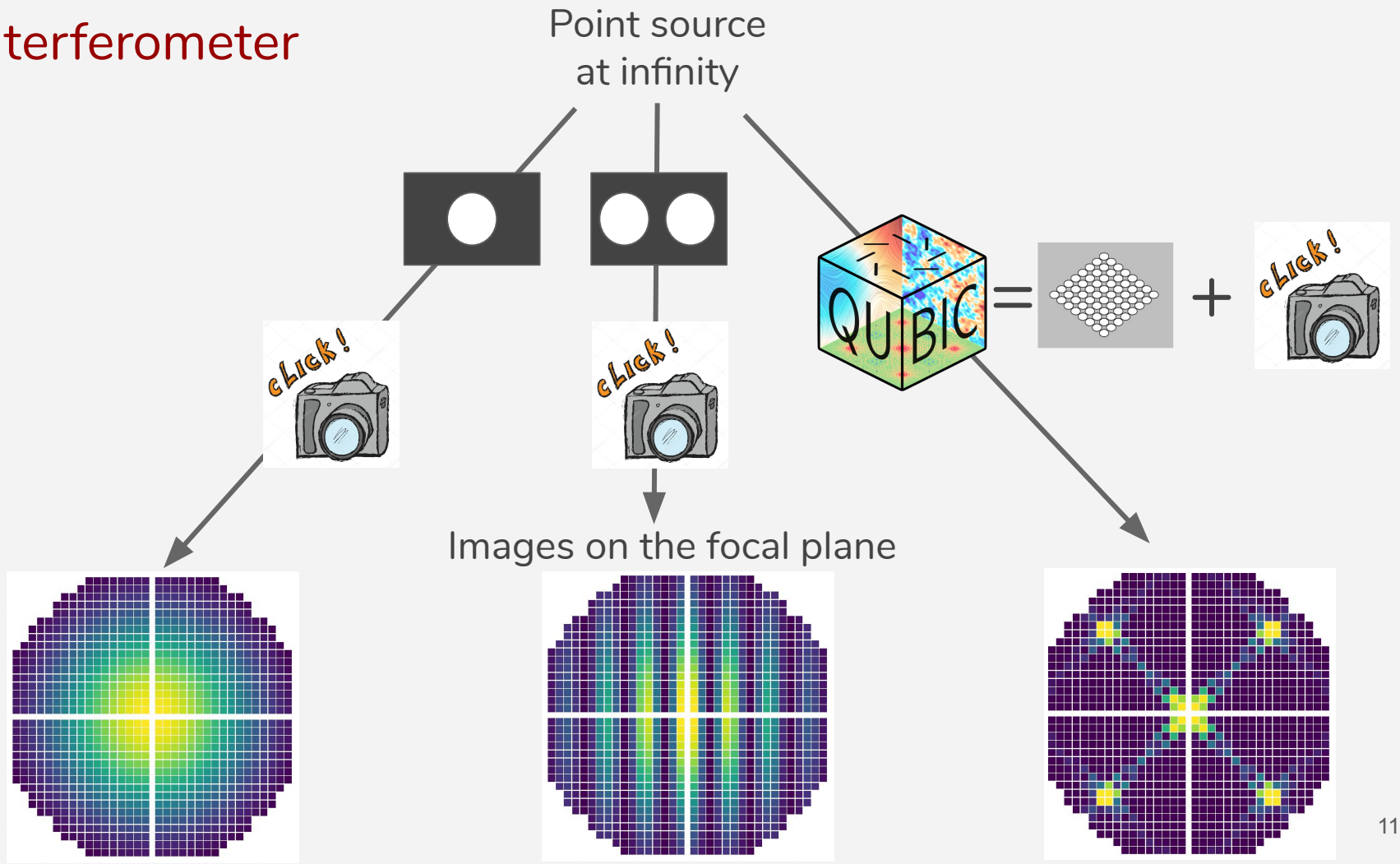


Integration hall in Salta

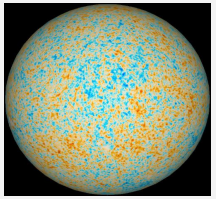
Optical part



An interferometer

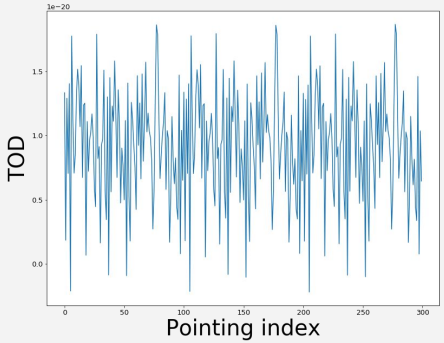


Data simulation and map-making



- Time Order Data (TOD)

TOD for one bolometer



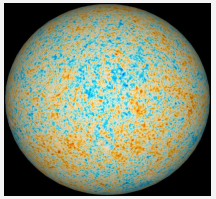
Matrix containing the pointing strategy over the sky

Map

Noise

$$\mathbf{d}_{bolo} = A\mathbf{T} + \mathbf{n}_{bolo}$$

Data simulation and map-making



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Matrix containing the pointing strategy over the sky

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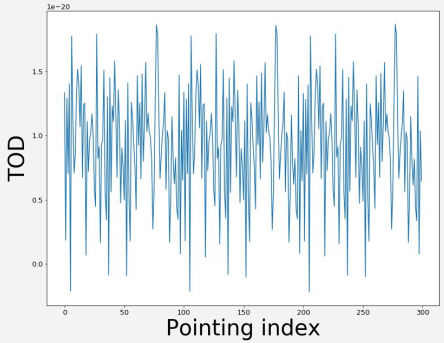
TOD for one bolometer



Noise

$$\mathbf{d}_{bolo} = A\mathbf{T} + \mathbf{n}_{bolo}$$

- Map-making in temperature and polarization

Covariance noise matrix

$\vec{d}$ → $T = \left(A^t \cdot N^{-1} \cdot A\right)^{-1} \cdot A^t \cdot N^{-1} \cdot \vec{d}$

TOD from the 992 bolometers

Map: Maximum-Likelihood solution

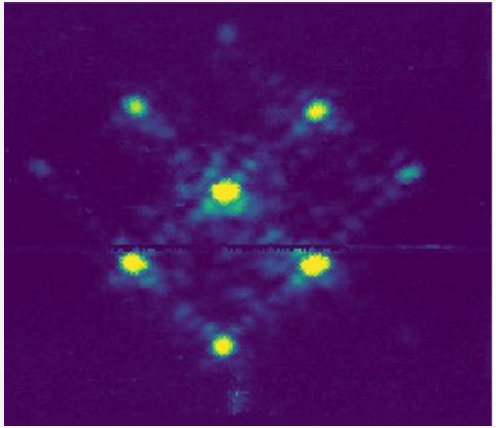
=> Not so easy !
For one day of observation, N is already a (3e6 x 3e6 x 992) operator.

Spectro-imaging

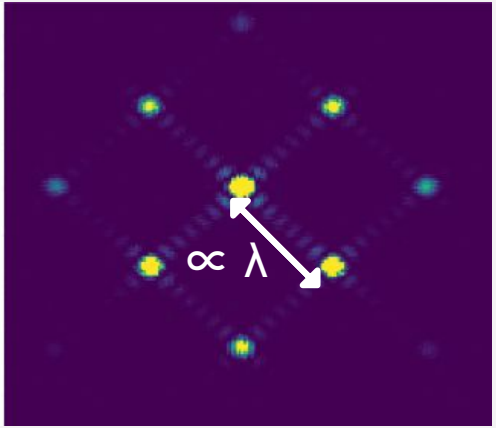
Goal: Make sky maps in many frequency sub-bands.

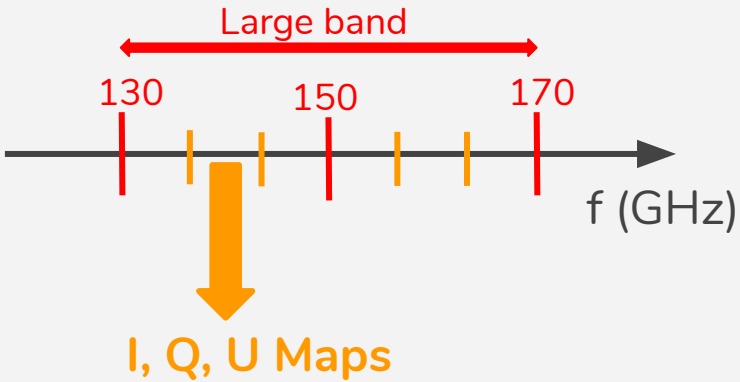
Example for bolometer 93 at **130GHz**:

Measurement



Theory



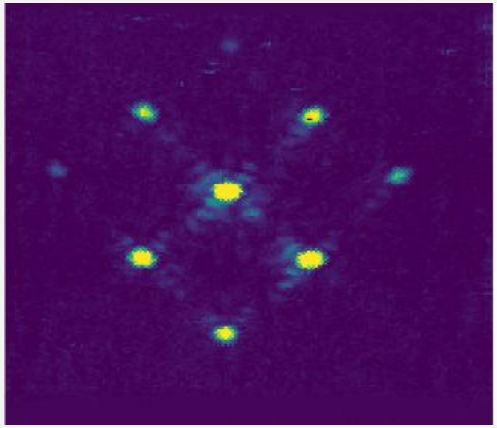


Spectro-imaging

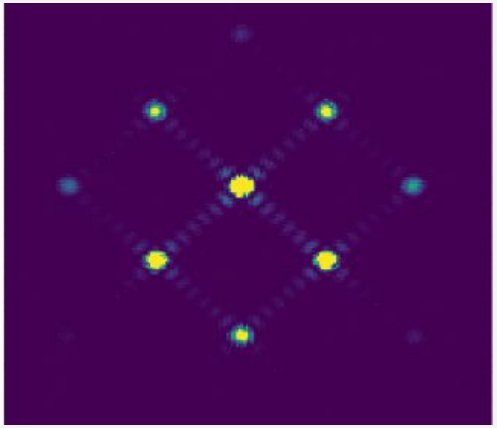
Goal: Make sky maps in many frequency sub-bands.

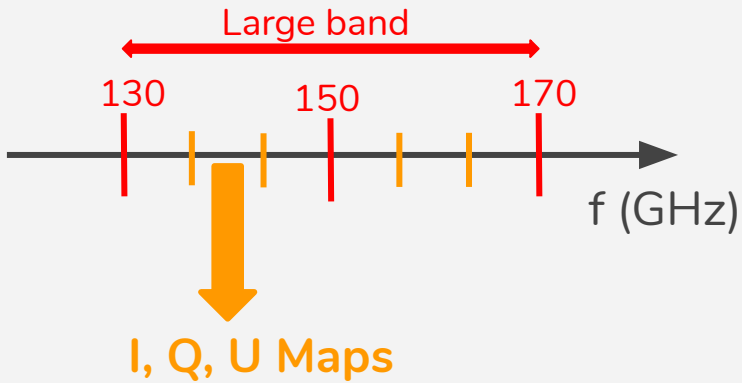
Example for bolometer 93 at **150GHz**:

Measurement



Theory



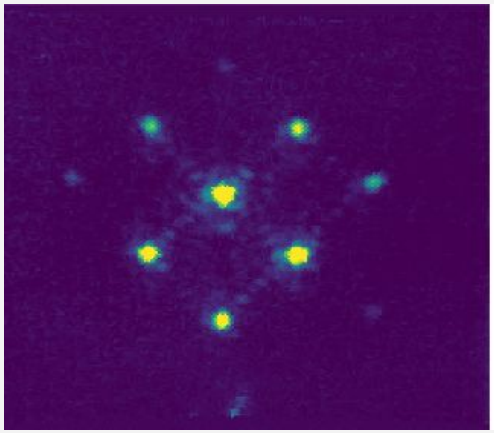


Spectro-imaging

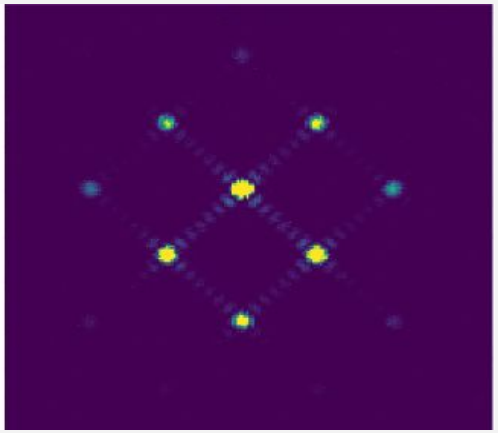
Goal: Make sky maps in many frequency sub-bands.

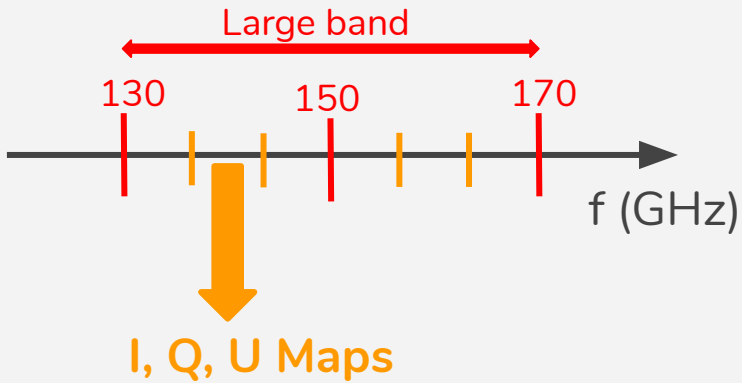
Example for bolometer 93 at **170GHz**:

Measurement

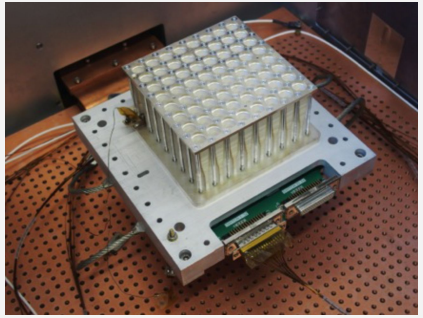


Theory

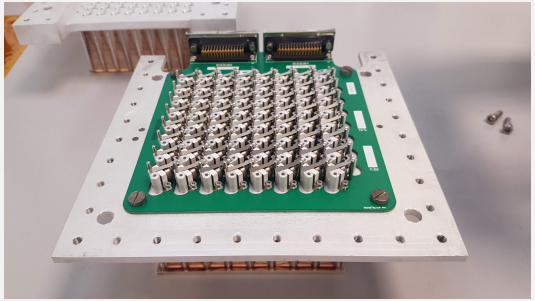




Self-calibration



Horn array (8x8)



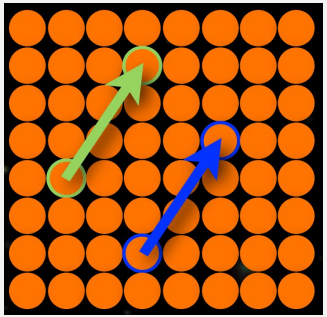
Switches

Method :

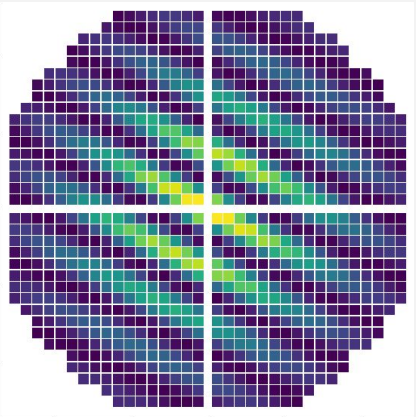
For 2 equivalent baselines, in case of a perfect instrument, you should obtain the same interference pattern on the focal plane.

The measured differences are used to characterize systematic effects.

2 redondant baselines
on the horn array

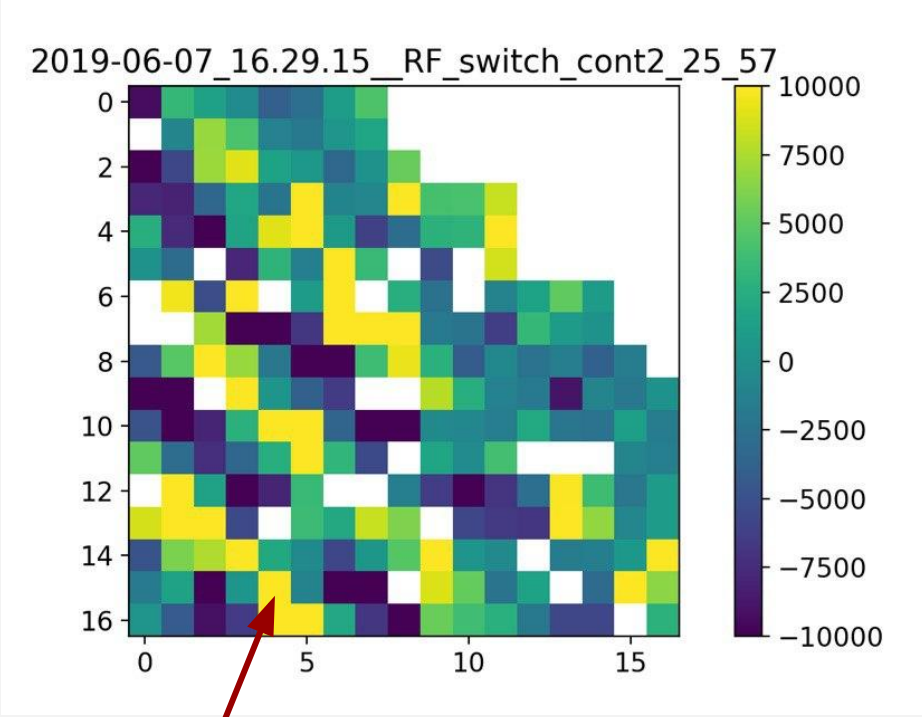


Fringes on the focal plane
created by one baseline

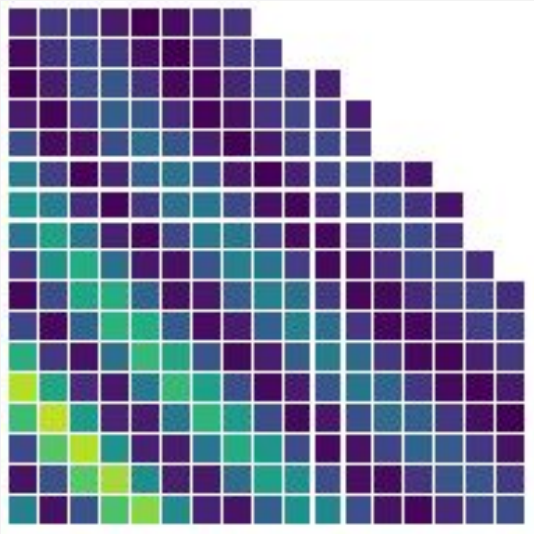


Fringes measurement

A quarter of the focal plane (17x17)



One bolometer



Simulation taking into account optical aberrations

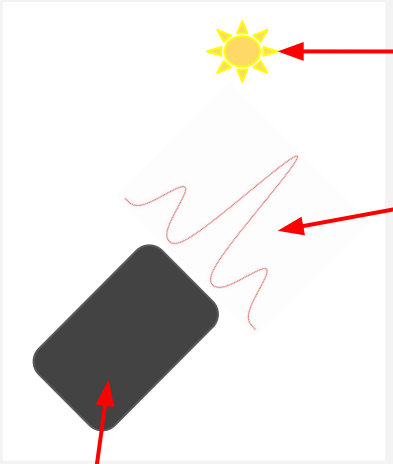
Conclusion

- The instrument is now calibrated at APC
- Will be installed in Argentina.
- Goal: learning about primordial universe (inflation)
- New possibilities:
  - Self-calibration
  - Spectro-imaging
- New project: QUBIC + LLAMA

Radio telescope APEX in Chile similar to LLAMA

Backup slides

Synthetized beam on the sky



Point source
(150 GHz)

Synthetized beam
for one detector

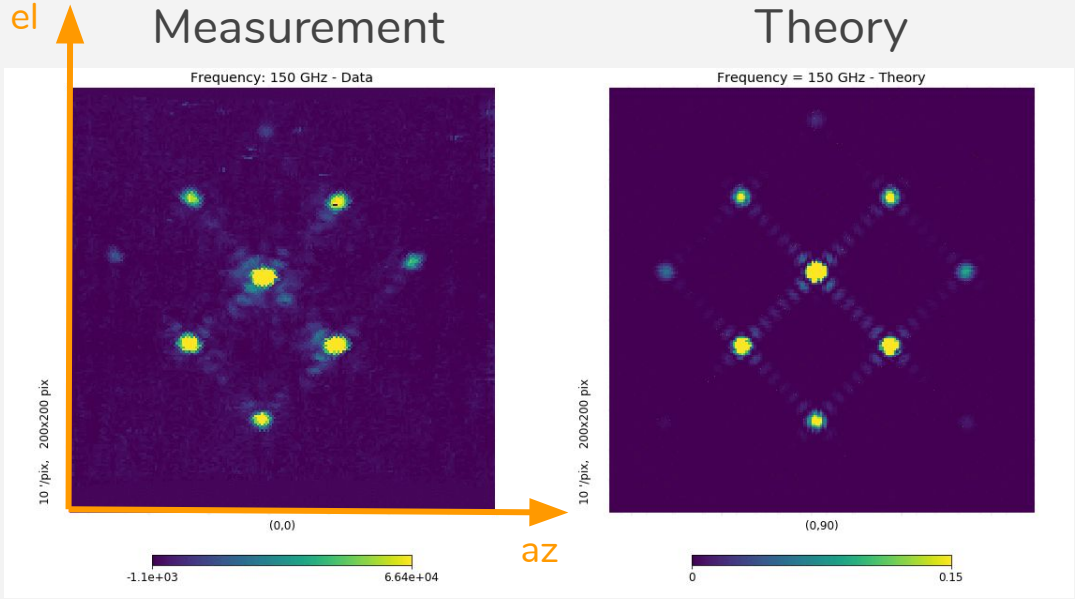
QUBIC

Scan in azimuth
and elevation

Example for bolometer 93:

Measurement

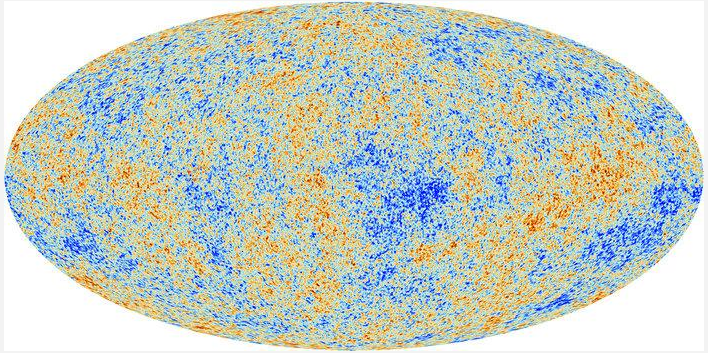
Theory

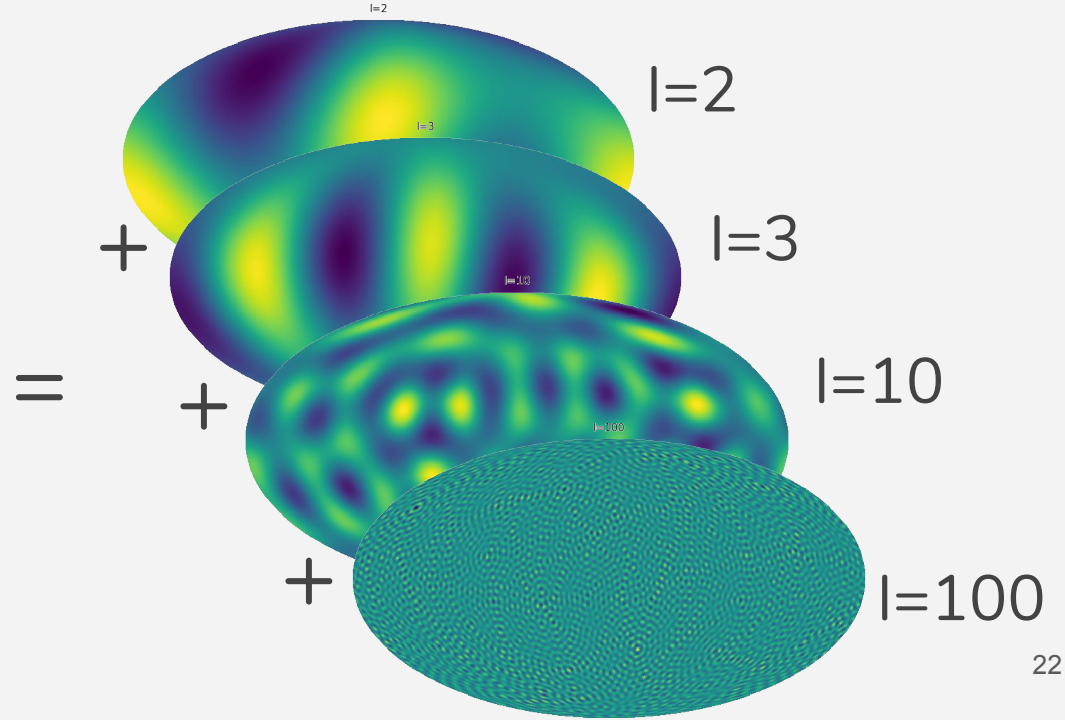


Spherical harmonic transform

$$T(\mathbf{n}) = T_0 + T_0 \sum_{l=1}^{\infty} \sum_{m=-l}^{l} a_{lm} Y_{lm}(\mathbf{n}) \qquad \text{with } a_{lm} = \int_{4\pi} T(\mathbf{n}) Y^*_{lm}(\mathbf{n})$$

$$l \sim \frac{\pi}{\theta}$$

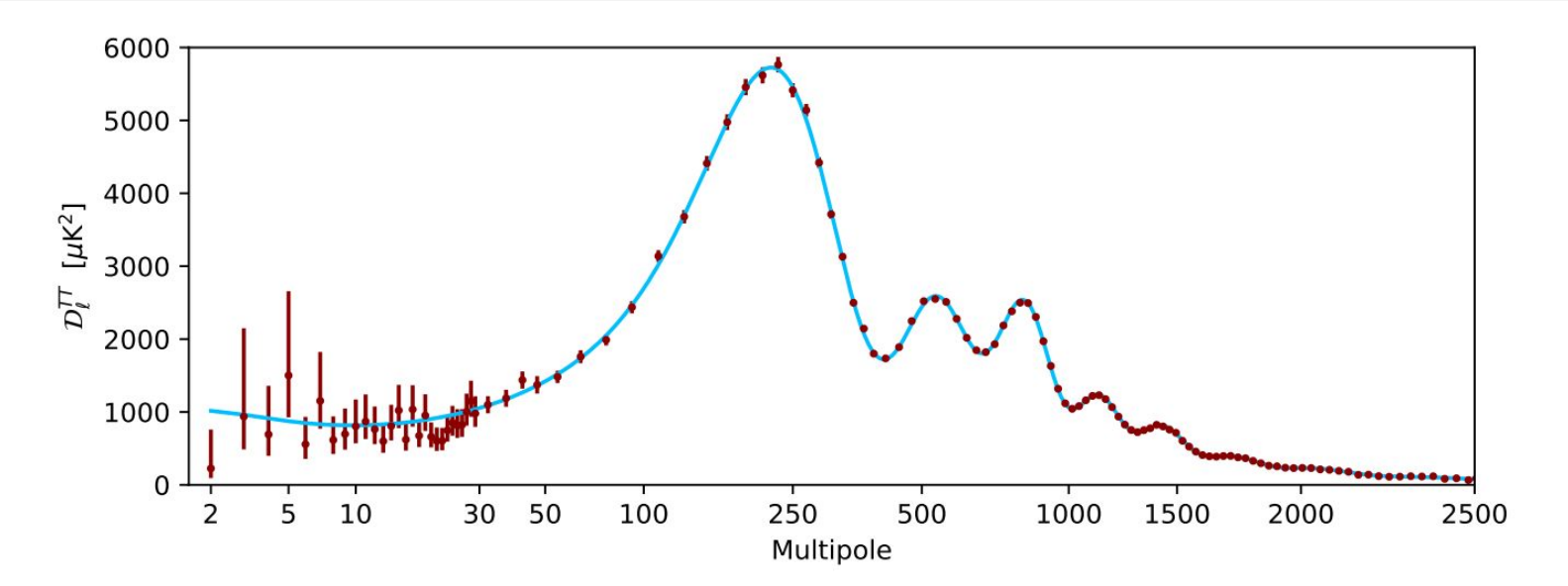




Power spectrum

Variance of the a_{lm}: $C_l = \langle a_{lm}^* a_{lm} \rangle_m = \frac{1}{2l+1} \sum_{m=-l}^{l} |a_{lm}|^2$

$$D_l = \frac{l(l+1)}{2\pi} C_l$$



Credit: *Planck, 2018*

E and B modes

$$(Q \pm iU)(\mathbf{n}) = \sum_{l=2}^{\infty} \sum_{m=-l}^{l} a_{\pm 2lm} \; {}_{\pm 2}Y_{lm}(\mathbf{n})$$

You can form 2 scalar quantities :

- E modes

$$E(\mathbf{n}) = \sum_{l=2}^{\infty} \sum_{m=-l}^{l} a^E_{lm} \; Y_{lm}(\mathbf{n}) \quad \text{with} \quad a^E_{lm} = -\frac{a_{2lm} + a_{-2lm}}{2}$$

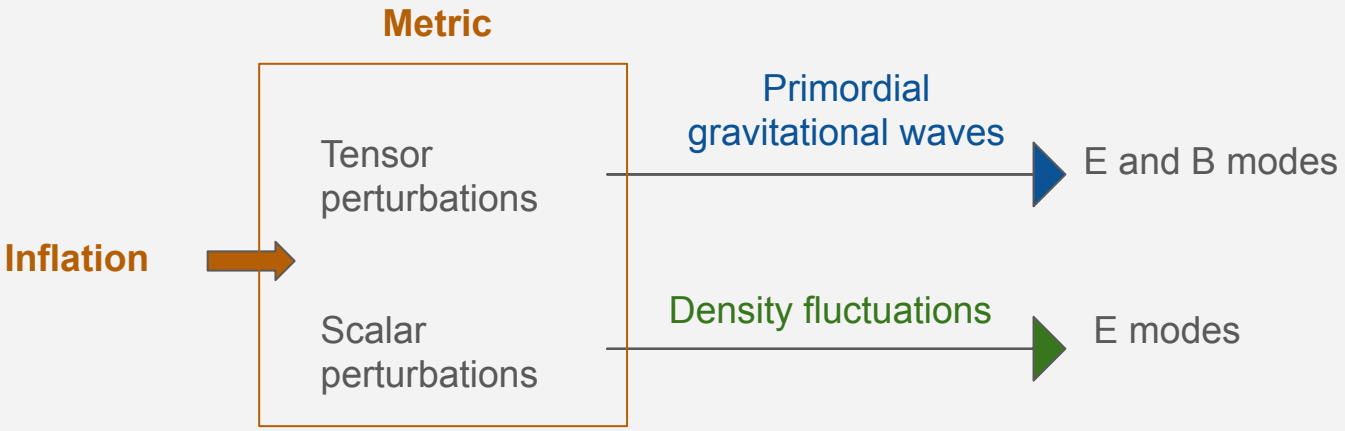
- B modes

$$B(\mathbf{n}) = \sum_{l=2}^{\infty} \sum_{m=-l}^{l} a^B_{lm} \; Y_{lm}(\mathbf{n}) \quad \text{with} \quad a^B_{lm} = i\frac{a_{2lm} - a_{-2lm}}{2}$$

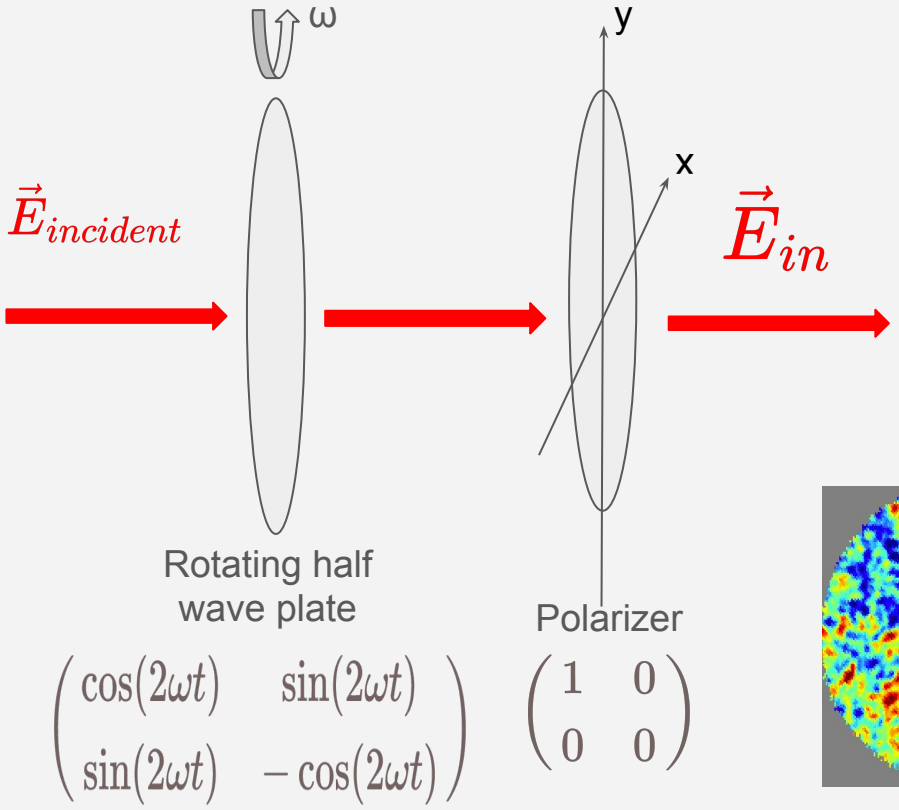
⇒ A global definition over the sky

Primordial B modes, a clue for inflation

Inflation :
Accelerated expansion phase right after the Big-Bang (~10^{-34} s)



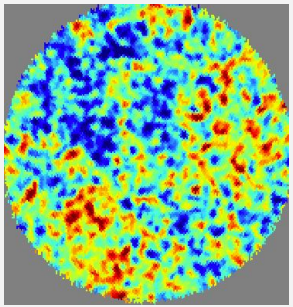
Polarization measurement

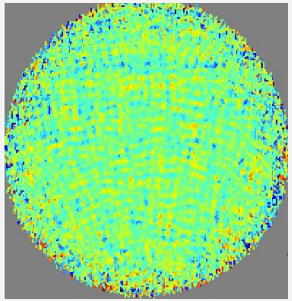


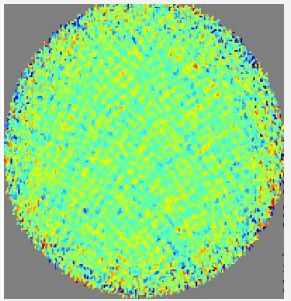
$$I_{in} = \left|E_x \cos(2\omega t) + E_y \sin(2\omega t)\right|^2$$
$$= I + Q\cos(4\omega t) + U\sin(4\omega t)$$

→ Using a correct rotating speed, we can reconstruct I, Q, U for each position on the sky.

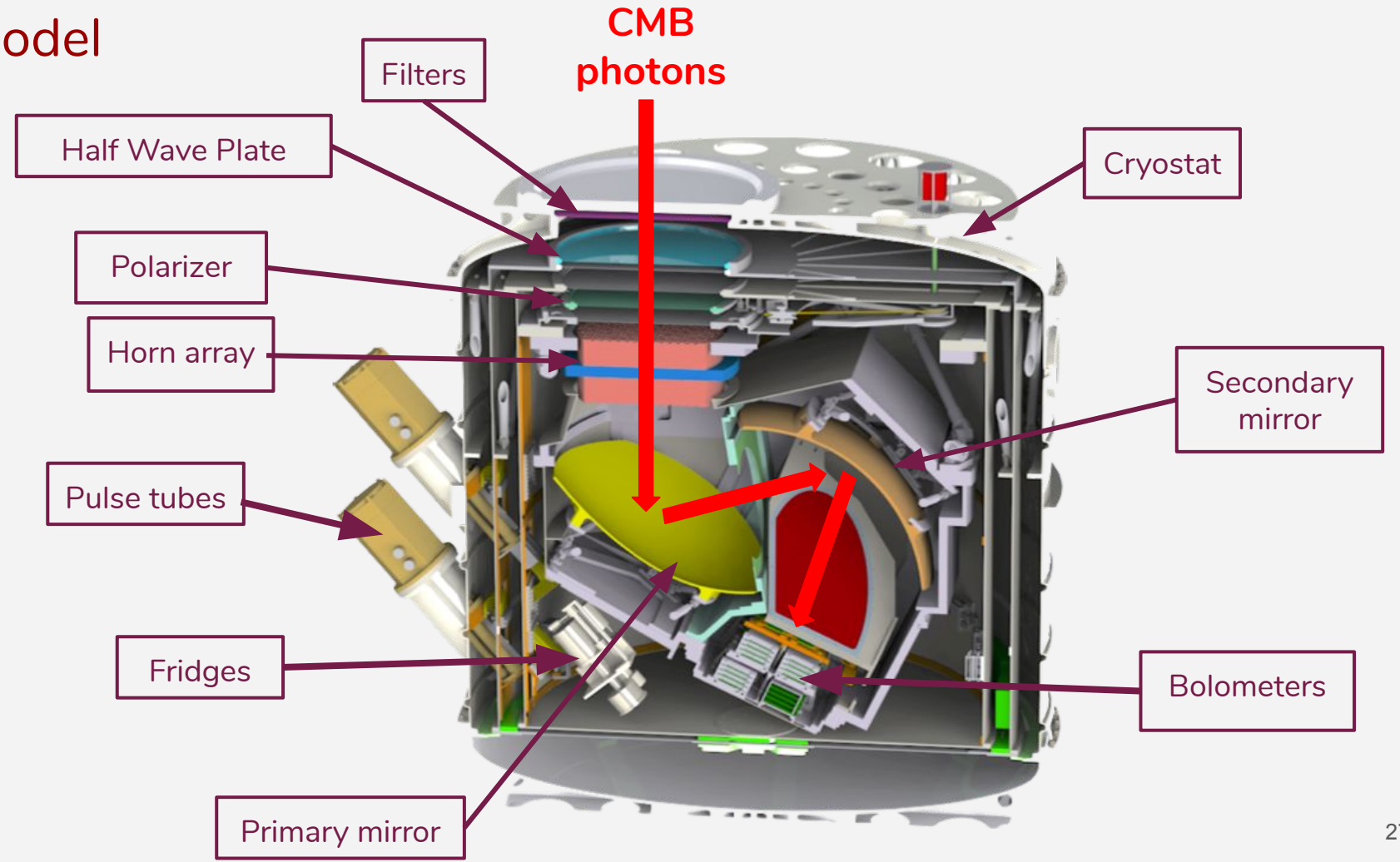
→ 3 sky maps


I

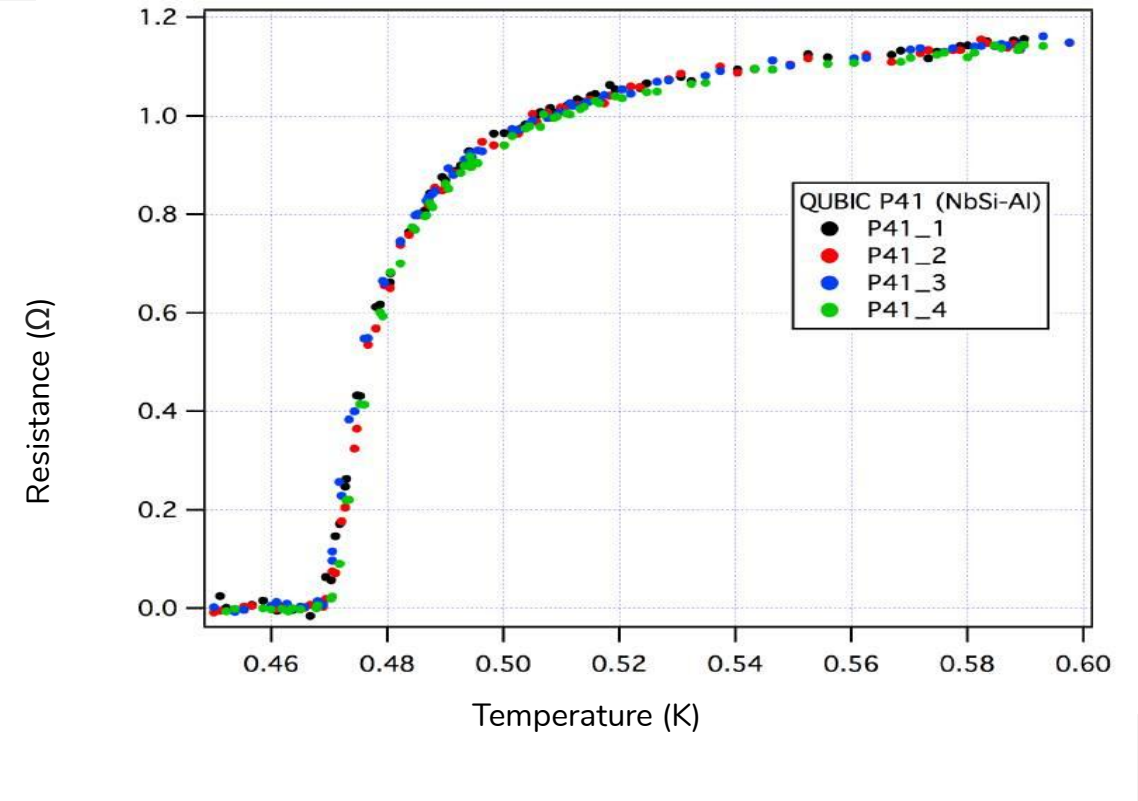

Q


U

3D model


CMB photons
Filters
Half Wave Plate
Polarizer
Horn array
Pulse tubes
Fridges
Primary mirror
Cryostat
Secondary mirror
Bolometers

Bolometer : Transition-Edge Sensor

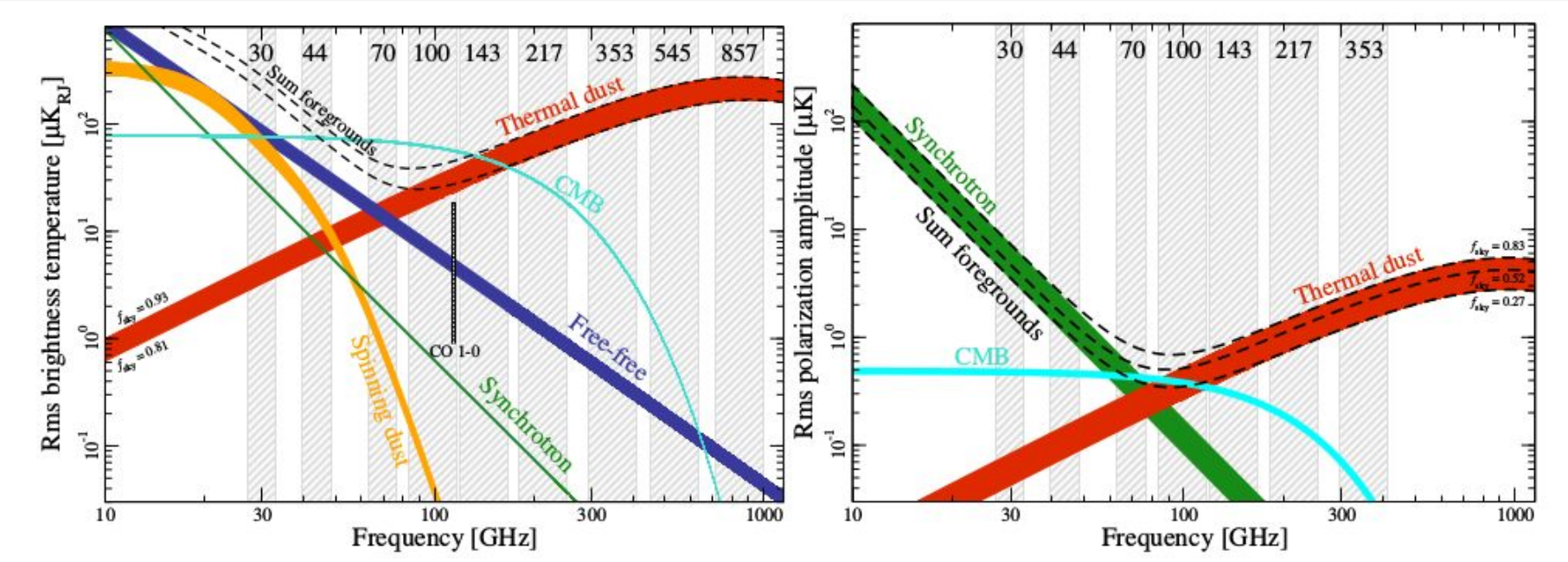


TES superconducting phase transition

Removing foregrounds

Temperature

Polarization



Credit: Planck, 2018

Title : Exploring the primordial universe with QUBIC: The Q&U Bolometric Interferometer for Cosmology

Abstract:

QUBIC is an experiment dedicated to the measurement of polarization B-modes of the Cosmic Microwave Background (CMB) using the novel technology of Bolometric Interferometry. In this talk, I will start with a brief explanation of the underlying physics: What are primordial B-modes and why it will give us invaluable insights on what happened during the inflation era, right after the Big Bang.
Then, I will present the current status of the project and the instrument architecture. The unique design of QUBIC brings new possibilities to CMB polarization mapping including self-calibration and spectroimaging.