



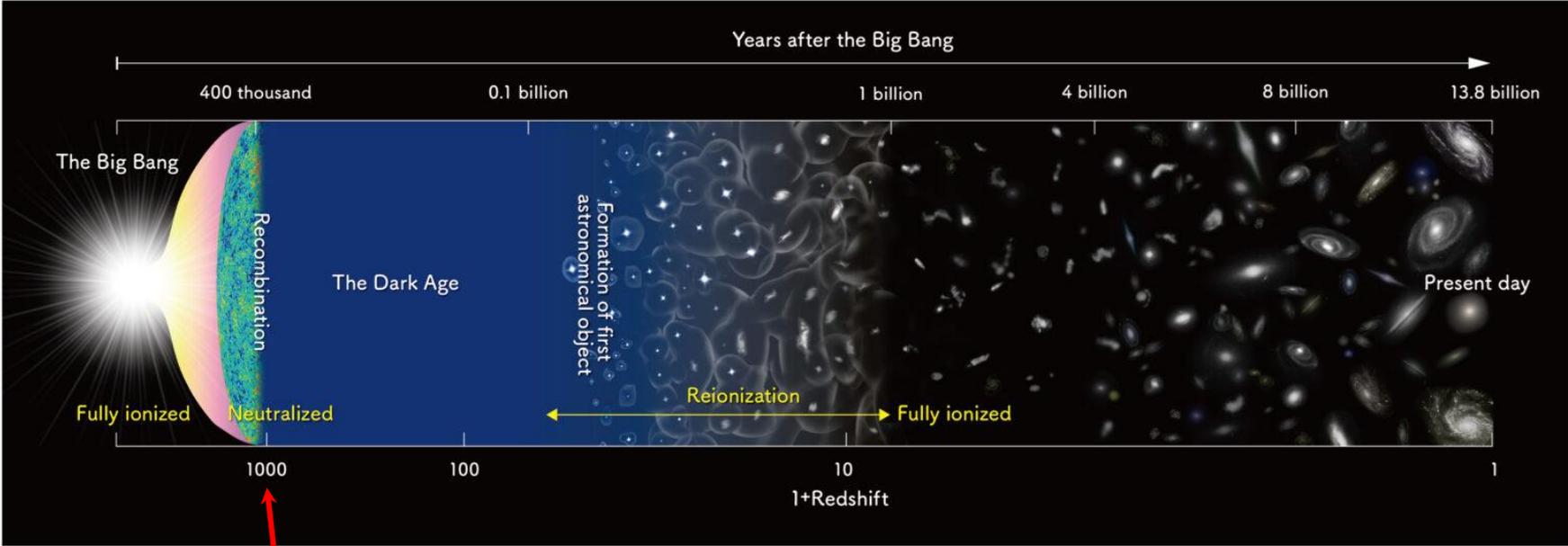
# The QUBIC Instrument: Design and Implementation of a Bolometric Interferometer for CMB Polarization

**Manuel Gonzalez** on behalf of the QUBIC collaboration

IUVSTA Workshop 109 APPEC Tech Forum Vacuum & Cryogenics - Industry meets Academia

24–26 Nov 2025  
Maastricht, NL

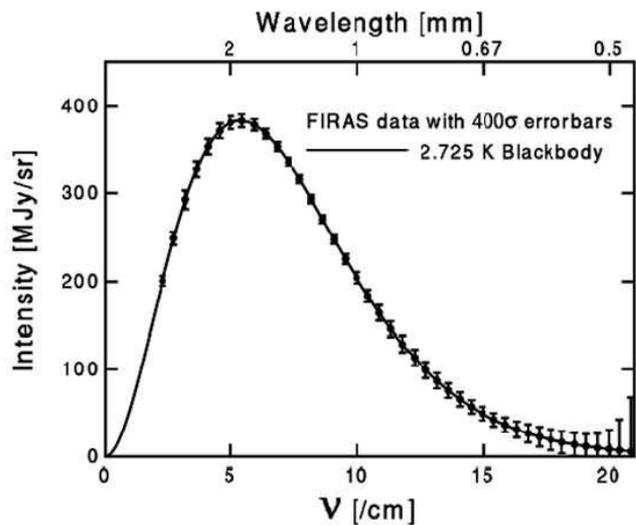
# Cosmic microwave background



CMB emission: when Universe became transparent e and p combined in H atoms

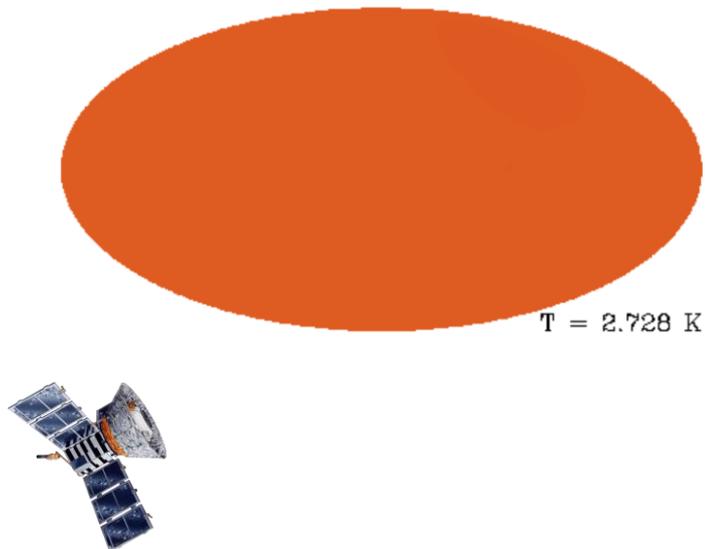
# CMB temperature

Almost perfect blackbody radiation



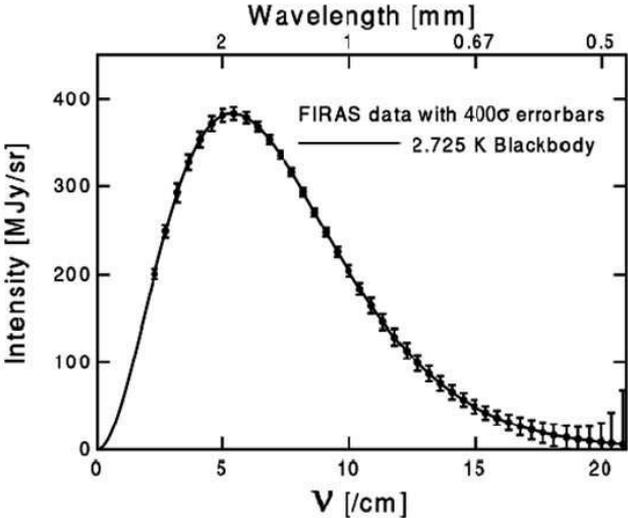
Spectral distortions, less than 1 in  $10^5$

COBE/DMR website



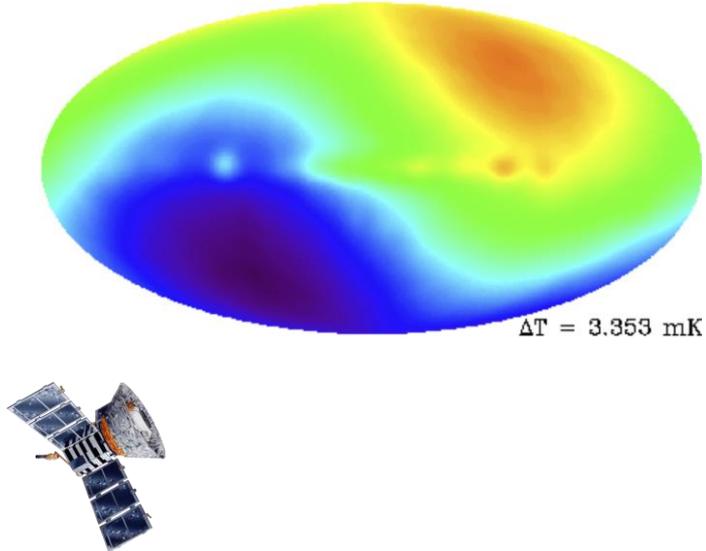
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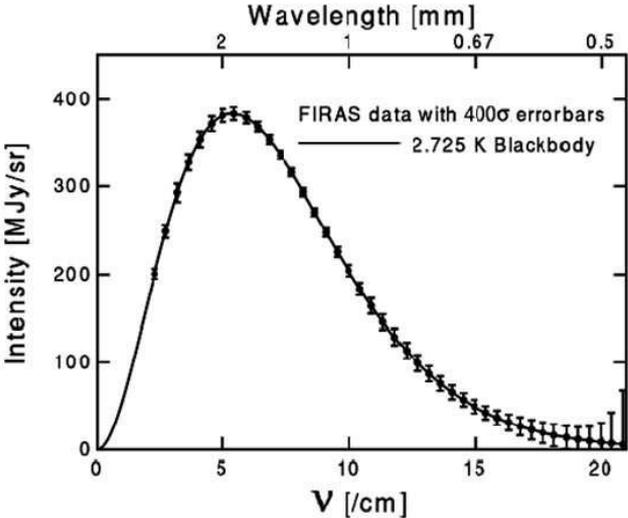
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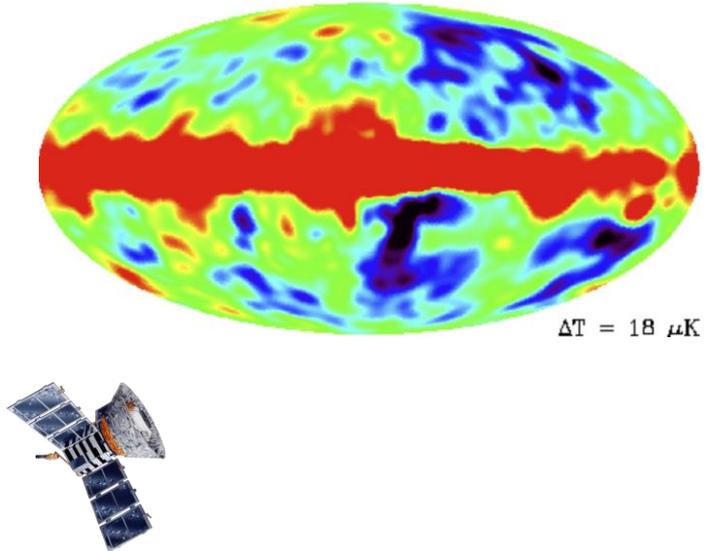
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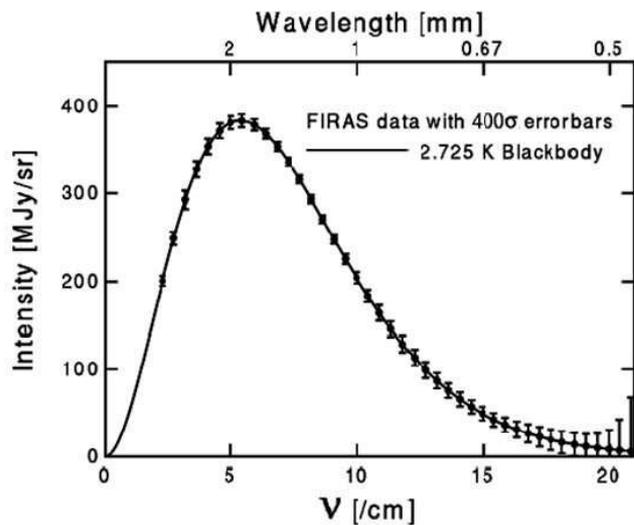
Spectral distortions, less than 1 in  $10^5$

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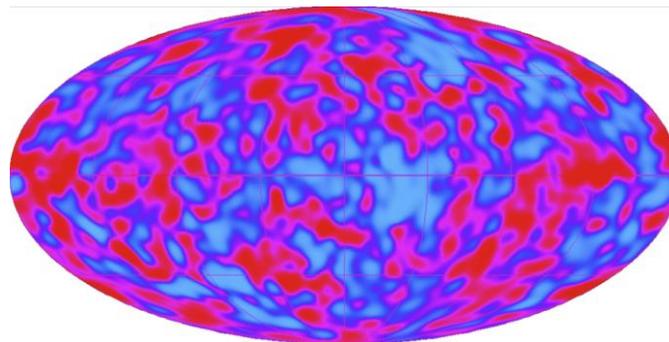
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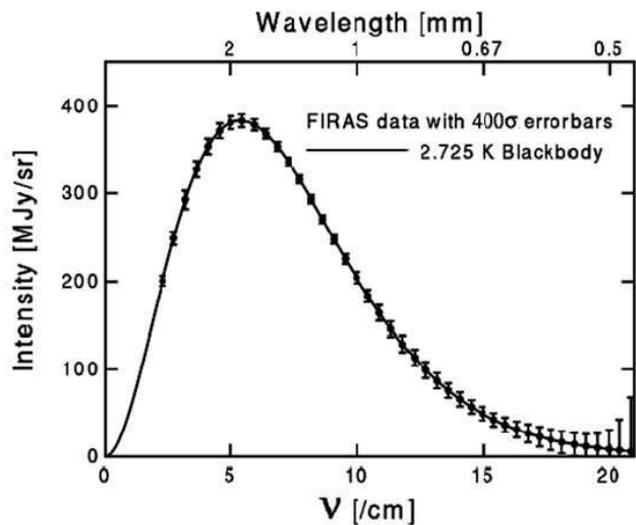
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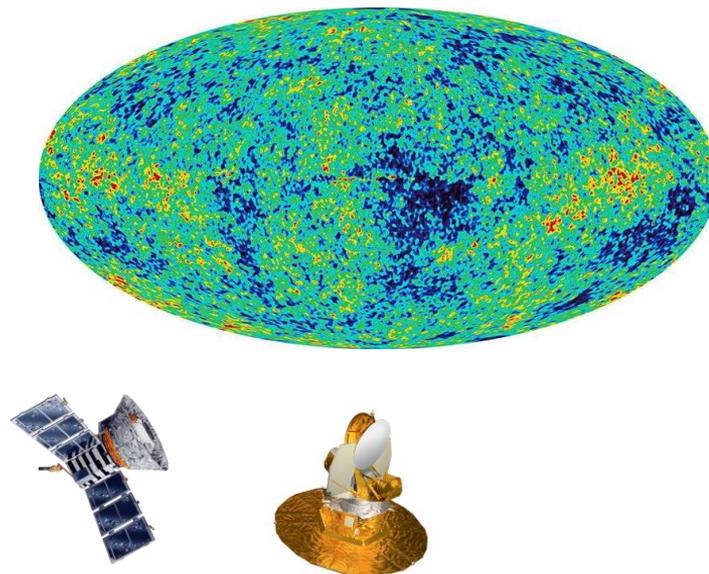
# CMB temperature

Almost perfect blackbody radiation



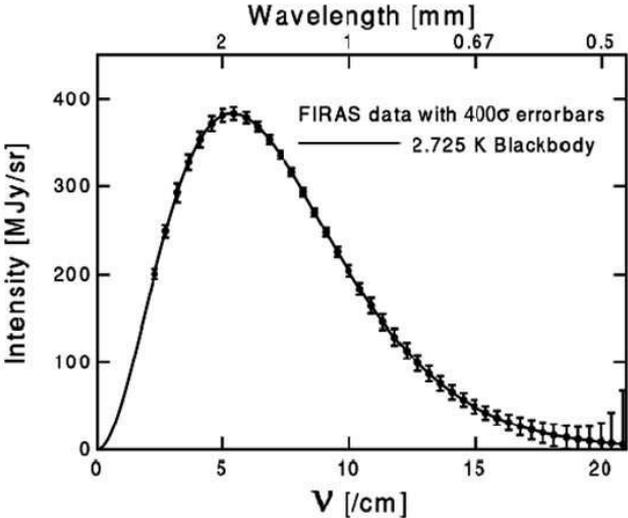
Spectral distortions, less than 1 in  $10^5$

WMAP



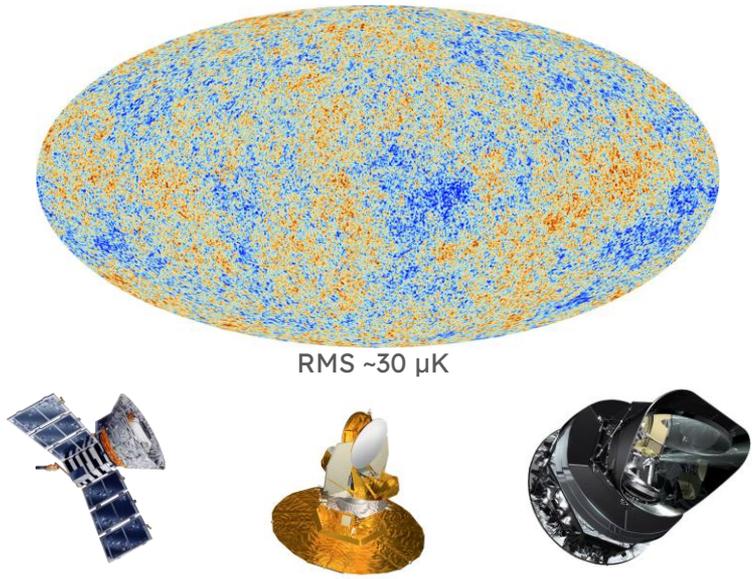
# CMB temperature

Almost perfect blackbody radiation



Spectral distortions, less than 1 in  $10^5$

Planck



RMS  $\sim 30 \mu\text{K}$

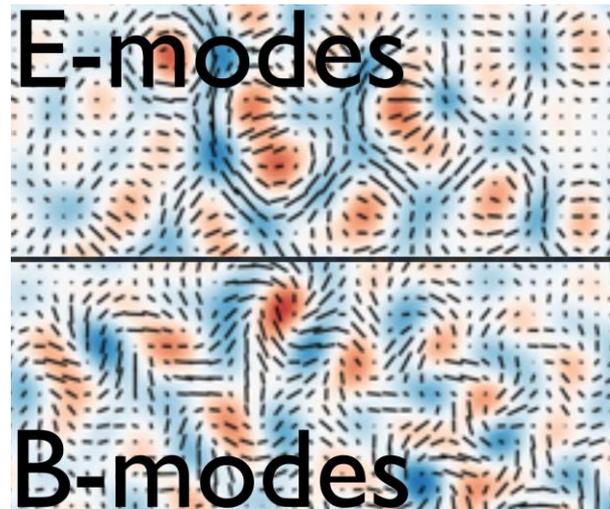
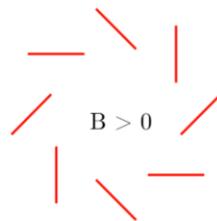
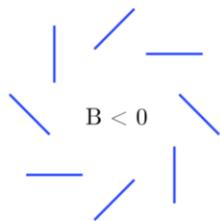
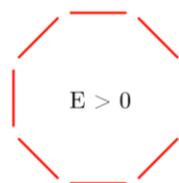
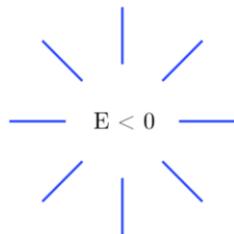
# CMB polarization

CMB is few % (linearly) polarized by Thomson scattering

Stokes parameters:

- **I** total intensity
- **Q** hor/vert linear pol
- **U** +-45° linear pol
- **V** left/right circ pol

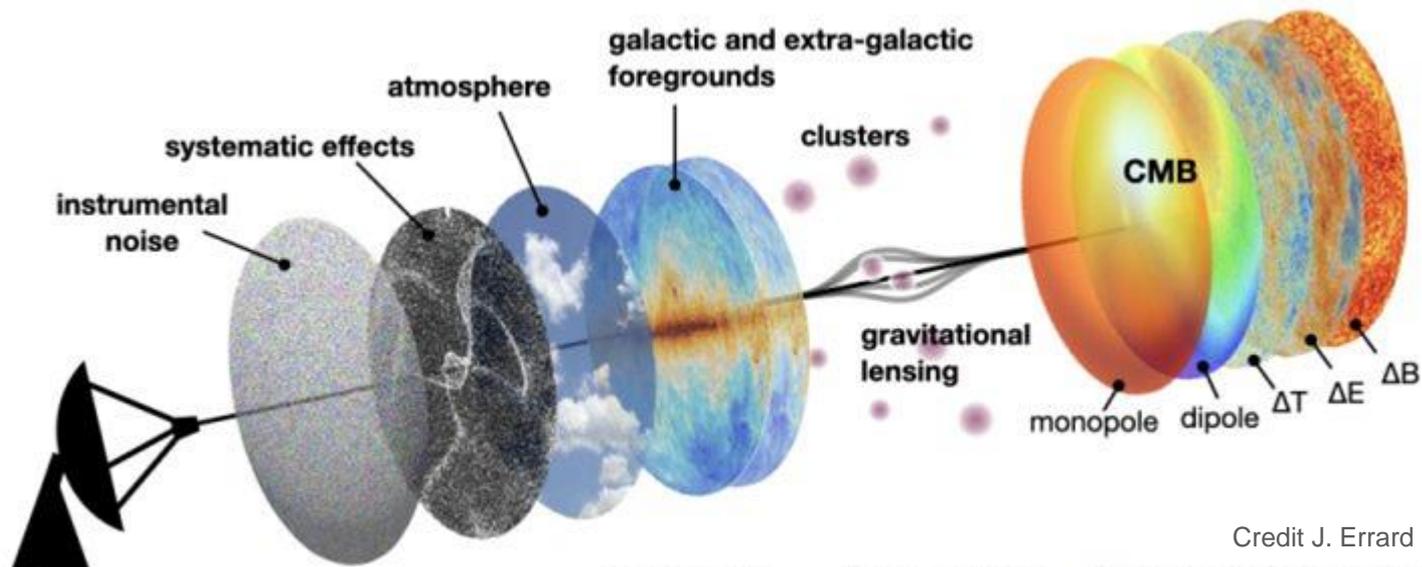
100% Q	100% U	100% V
<p><b>+Q</b></p> <p><math>Q &gt; 0; U = 0; V = 0</math></p> <p>(a)</p>	<p><b>+U</b></p> <p><math>Q = 0; U &gt; 0; V = 0</math></p> <p>(c)</p>	<p><b>+V</b></p> <p><math>Q = 0; U = 0; V &gt; 0</math></p> <p>(e)</p>
<p><b>-Q</b></p> <p><math>Q &lt; 0; U = 0; V = 0</math></p> <p>(b)</p>	<p><b>-U</b></p> <p><math>Q = 0; U &lt; 0; V = 0</math></p> <p>(d)</p>	<p><b>-V</b></p> <p><math>Q = 0; U = 0; V &lt; 0</math></p> <p>(f)</p>



Any linear polarization field can be decomposed into the two scalar fields E and B.

Primordial B-modes are a specific prediction from inflation

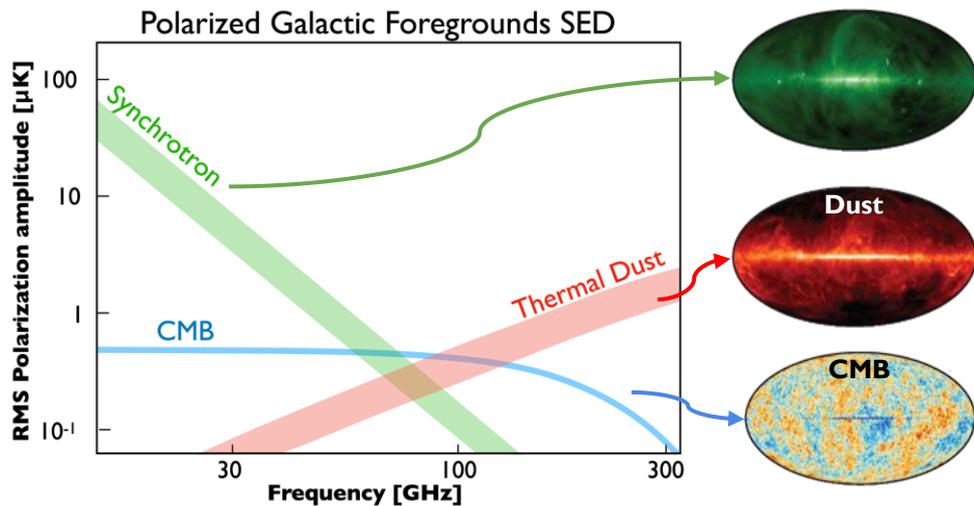
# Instrumental challenge



We want to measure **extremely faint signals**:

- **High altitude** and **dry** observation sites (even better from space, next pres.)
- **Many detectors** to integrate the signal + **cryogenic operation** (~ 100 mK) for low noise
- **Spectral measurements** allow us to disentangle the CMB from the foregrounds

# Instrumental challenge



## Small polarized signal:

- high sensitivity detectors
- low systematics  
( $T \gg E \gg B$ )

## Astrophysical foregrounds:

- Gravitational lensing
- Galactic foreground emission:
  - Synchrotron & Dust

# The QUBIC collaboration



- APC Paris, France
- IAS Orsay, France
- IRAP Toulouse, France
- Università di Milano-Bicocca, Italy
- Università degli studi di Milano, Italy
- Università 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



# The QUBIC collaboration II



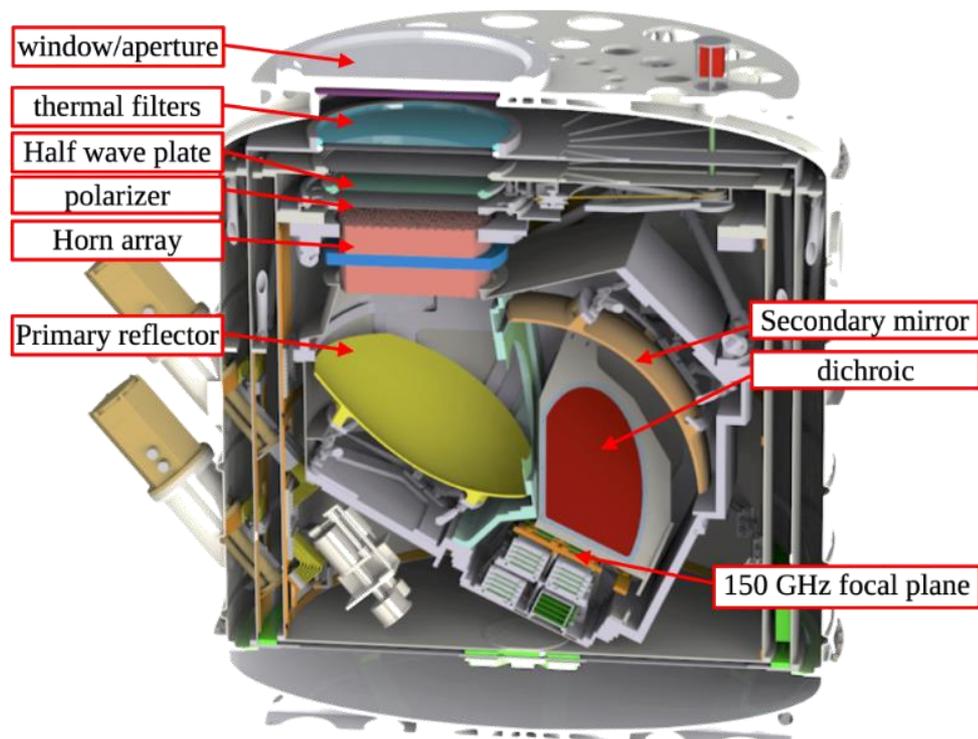
- Cryostat: **Italy: Roma**
  - 1K Box / detectors (300mK TES): **France: APC / CSNSM / IRAP**
  - Fridges: **UK: Manchester**
  - Optics: **Italy: Roma / Milano - Ireland: Maynooth - UK: Cardiff**
  - Mount: **Argentina: La Plata & CNEA**
  - Site: **Argentina: CNEA - Salta Province**
  - Calibration Mount: **France: IJCLab**
- Integration, Calibration and testing: **France: APC - Argentina: Salta**



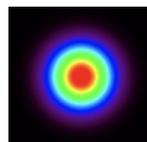
# The QUBIC instrument

## Bolometric interference

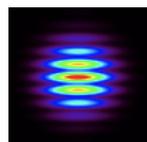
- High sensitivity
  - **Transition edge sensors  $T \sim 0.3$  K**
  - Cold optics and electronics
  - Absorption fridges at 1 K and 0.3 K
- Interferometry
  - **Spectro-imaging**
  - Systematics control
- Cryostat
  - Temperature stages (40 K, 4 K, 1 K)
  - Window and **IR filters** at every stage
  - Detectors stage at 0.3 K
- Dimensions
  - 1.5 m x 1.42 m
  - **800 kg**



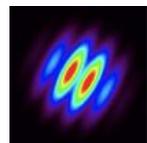
# The QUBIC Concept: adding interferometry



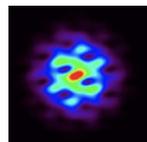
1 Horn open



2 Horns open

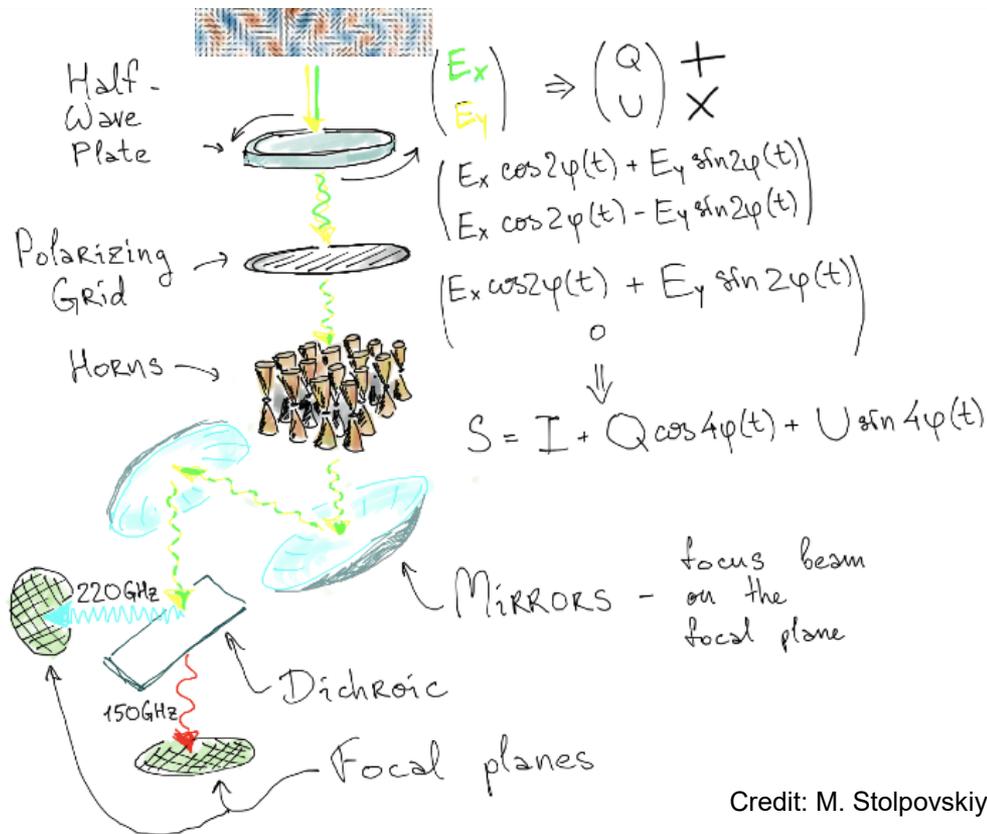
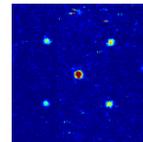
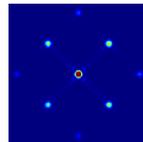
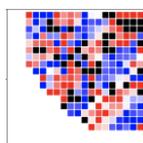
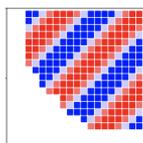
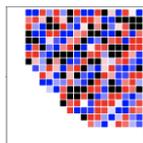
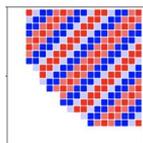


2 Horns open



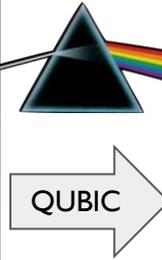
All Horns open

[L. Mousset, PhD, 2021]  
 QUBIC Sim.    QUBIC Cal Data

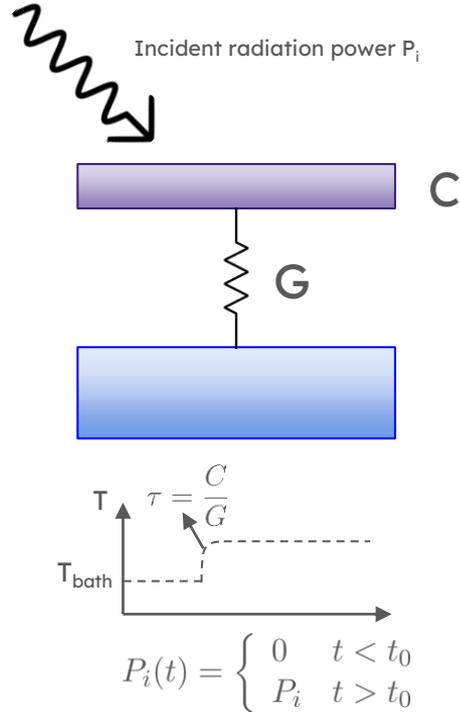


Credit: M. Stolpovskiy

# The QUBIC concept: interferometry



# Bolometers



- Detection of a flux of radiation with incident power  $P_i$

$$\Delta T = \frac{P_i}{G}$$

- Figure of merit noise equivalent power:

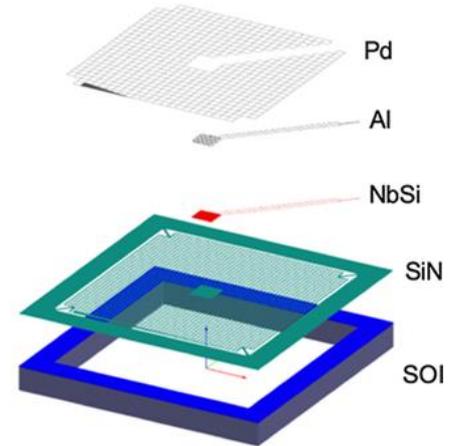
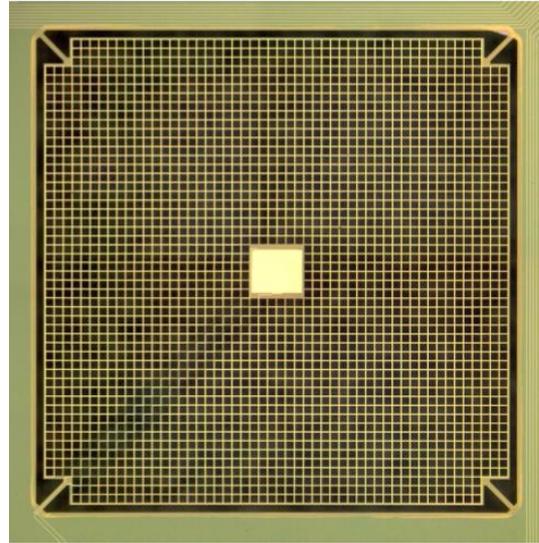
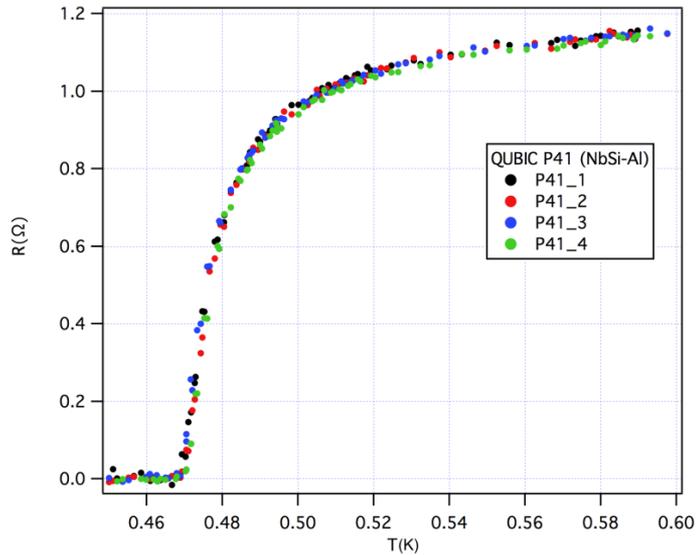
$$NEP = \sqrt{4K_B T^2 G} [\text{W}/\sqrt{\text{Hz}}]$$

Interest to work at low temperature:

- Improved (fundamental) noise performances or energy resolution
- Faster detectors (lower thermal time constant, to be continued...)

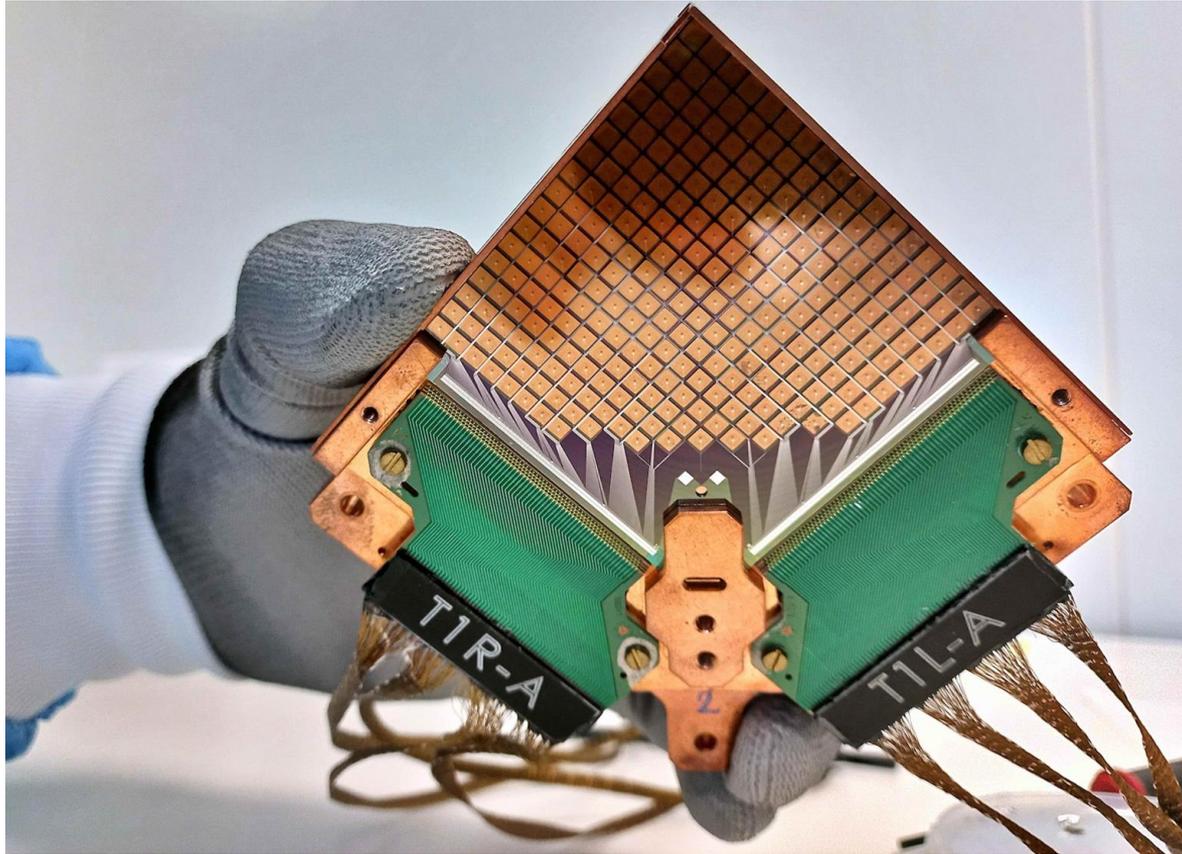
For ground based CMB observation,  $\sim 300$  mK is enough to be background limited

# Bolometers: transition edge sensors



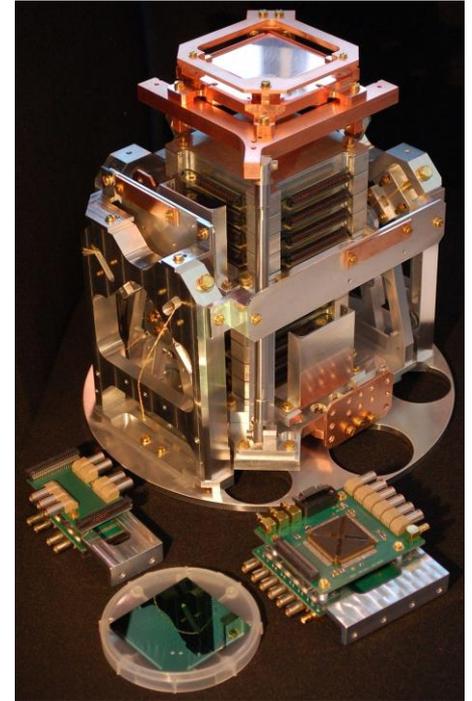
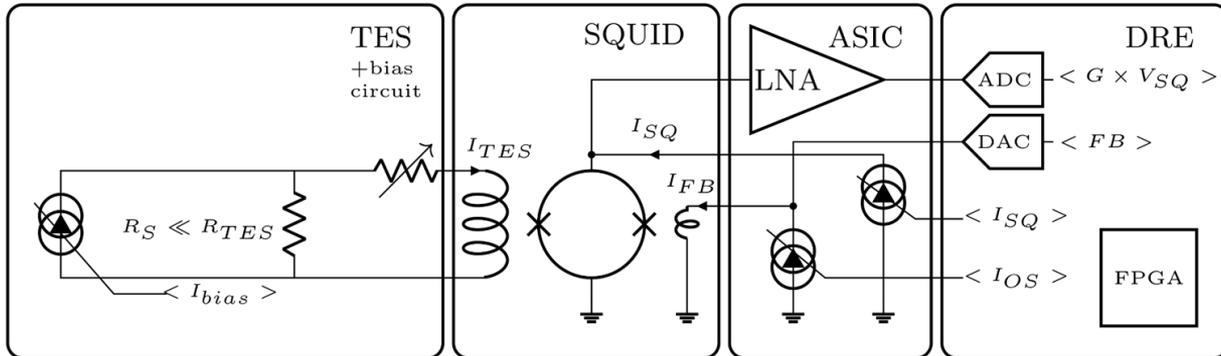
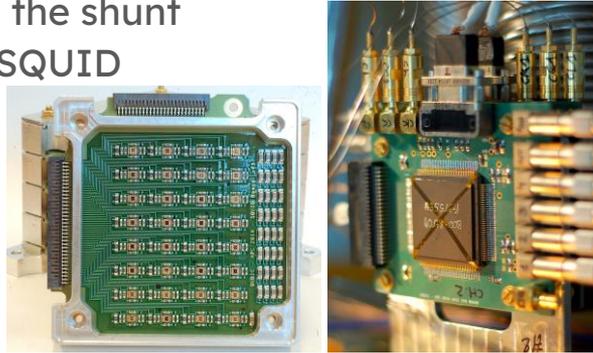
The  $T_c$  of the superconducting material determines the operation temperature

# Bolometers: transition edge sensors



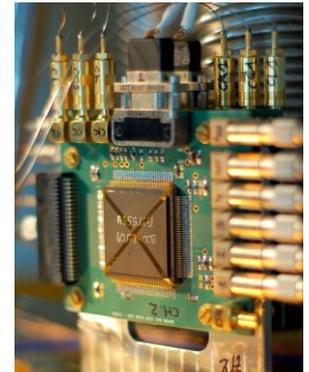
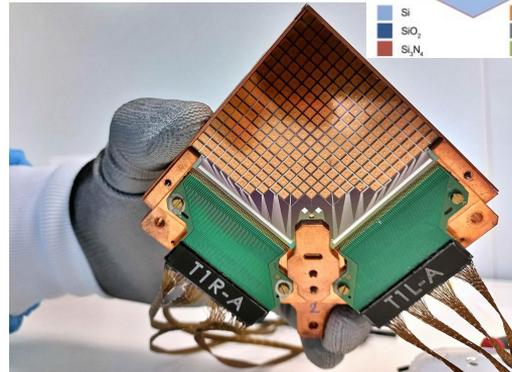
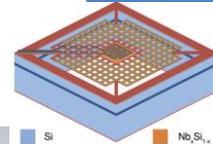
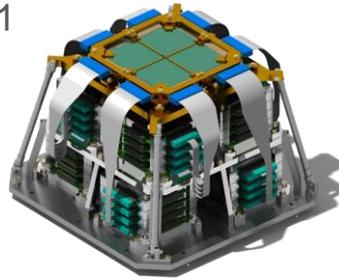
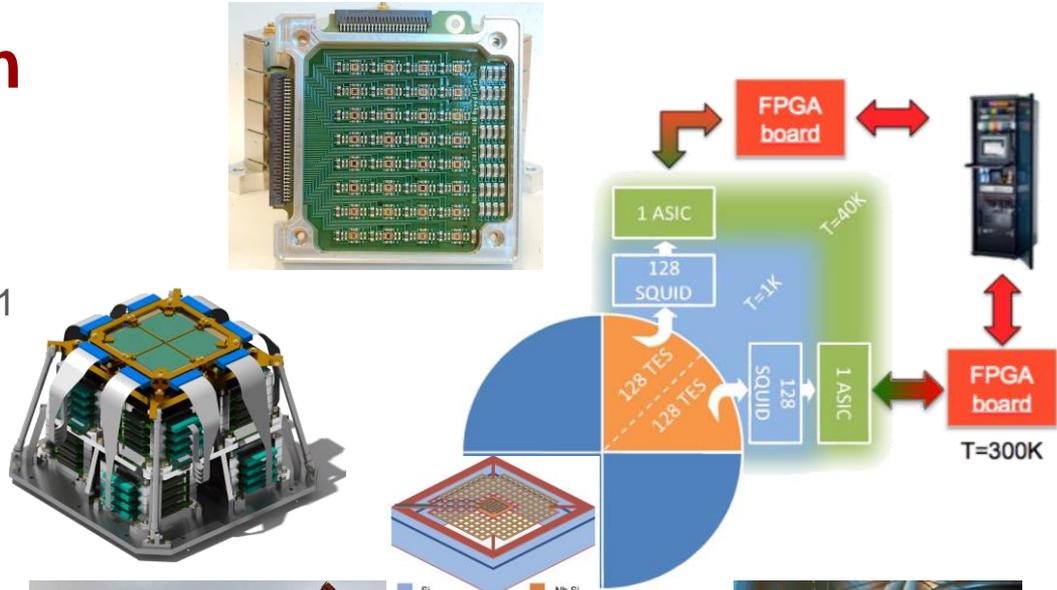
# Readout electronics

- Measure the TES current with an extremely low impedance  $\square$  SQUID!
- Power dissipation in the shunt
- FLL to linearize the SQUID



# QUBIC Detection chain

- 1 focal plane = 4 TES arrays x 256
- Cold electronics:
  - Time-division multiplexing 128:1
  - 128 SQUIDs @ 1 K
  - 1 SiGe ASIC @ 40 K
- Warm readout:
  - FPGA board



Currently deployed TD:

1/4 focal plane (256 detectors) @ 150 GHz

# QUBIC cryogenics: general architecture

Pulse tubes: Sumitomo RP-082B2S

- 35 W @ 45 K
- 0.9 W @ 4 K

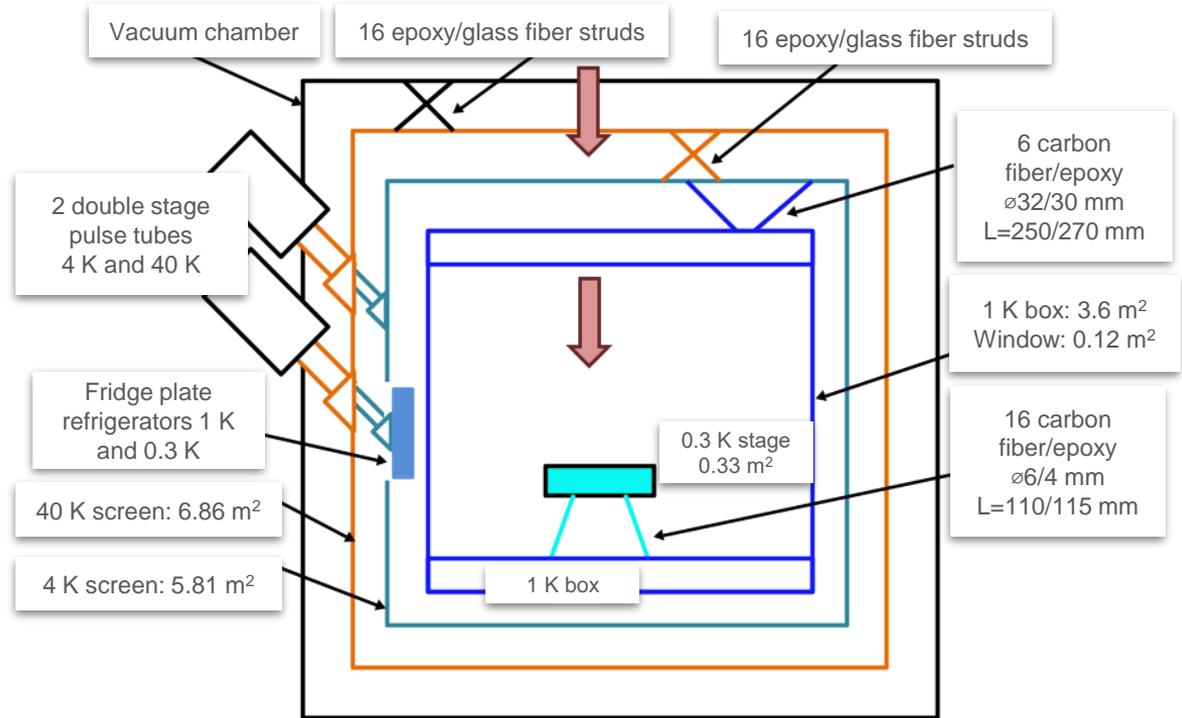
Advantages:

- Continuous cooling
- 4 K stage Temperature 2.6 K

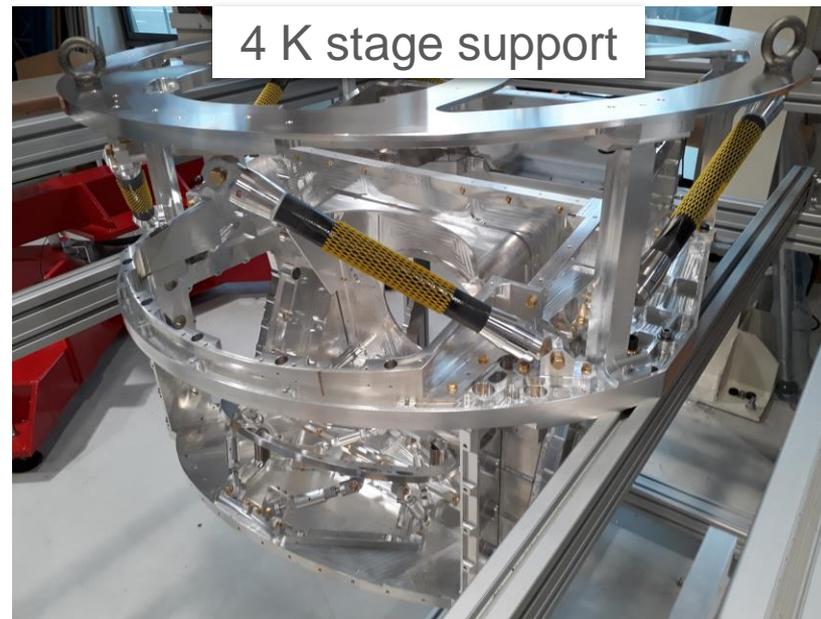
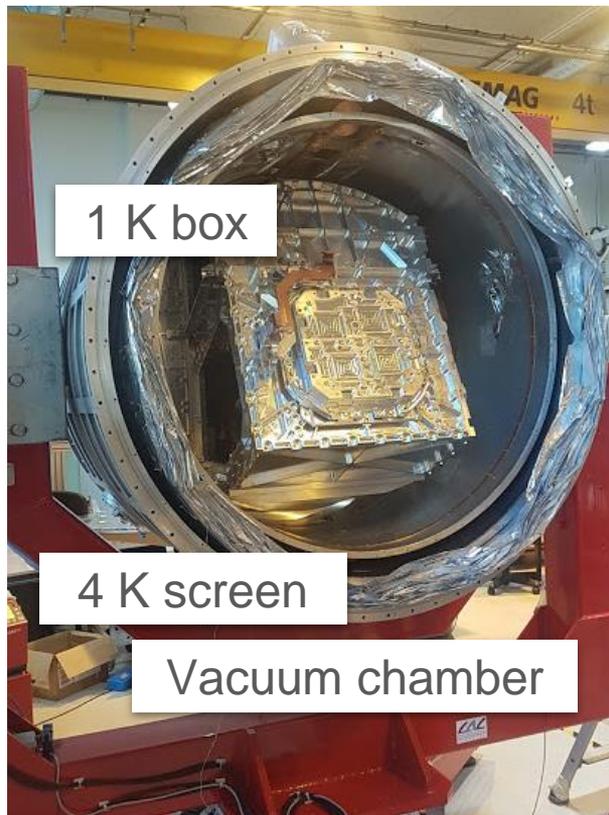
Disadvantages:

- Vibrations
- Low efficiency

The two 45 K stages in parallel



# QUBIC cryogenics: general architecture

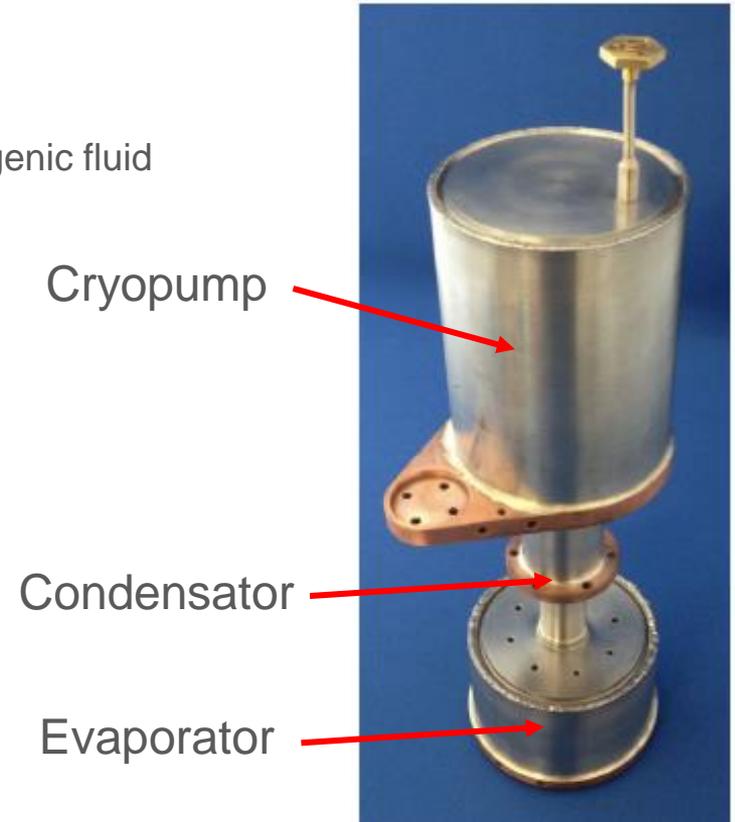
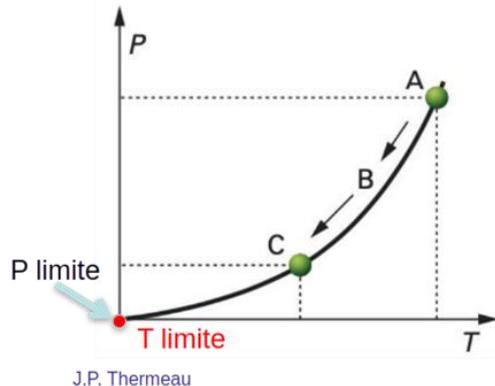


1 K box mass: 110 kg Al, 10 kg Cu

# Adsorption fridges

Operation principle:

- Cooling thanks to pressure decrease of a biphasic cryogenic fluid
- Pressure decrease: pumping
- Pumping thanks to adsorption: cold source
- Material with large specific surface: active charcoal
- Adsorption capacity decreases with temperature



# QUBIC cryogenics: Sub-Kelvin cryogenic design

Mechanical heat switches (Entropy):

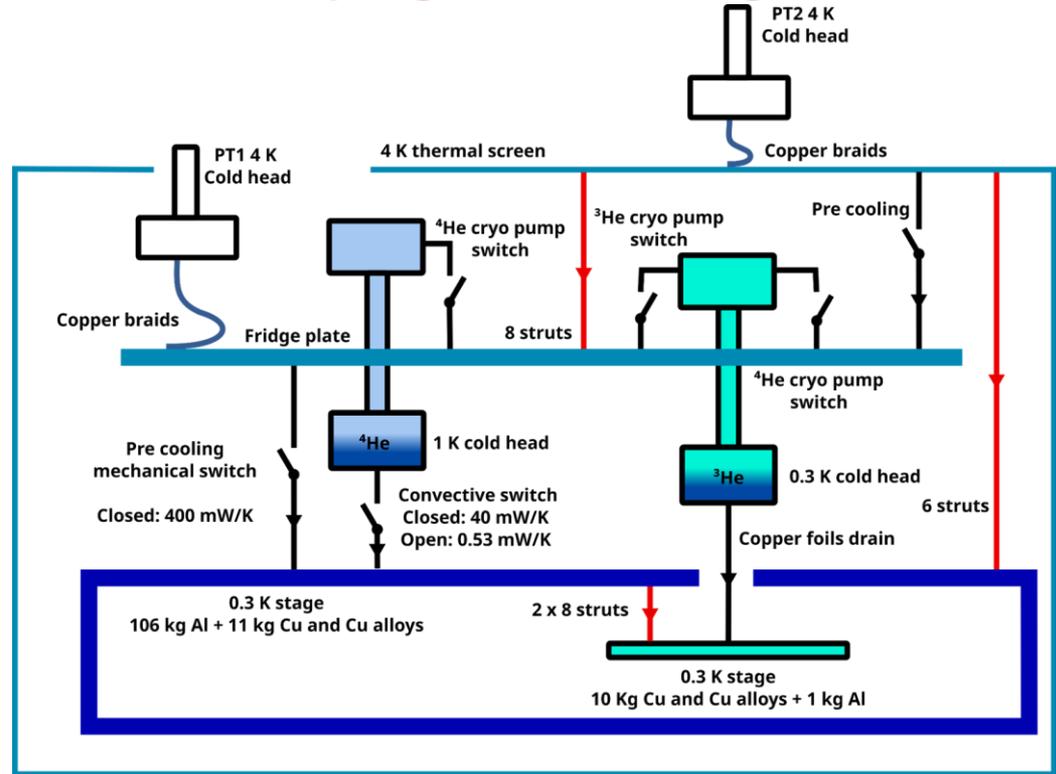
- Optimize coupling 4 K -> 1 K stage
- Open when 1 K stage reaches 4 K

Convective heat switches:

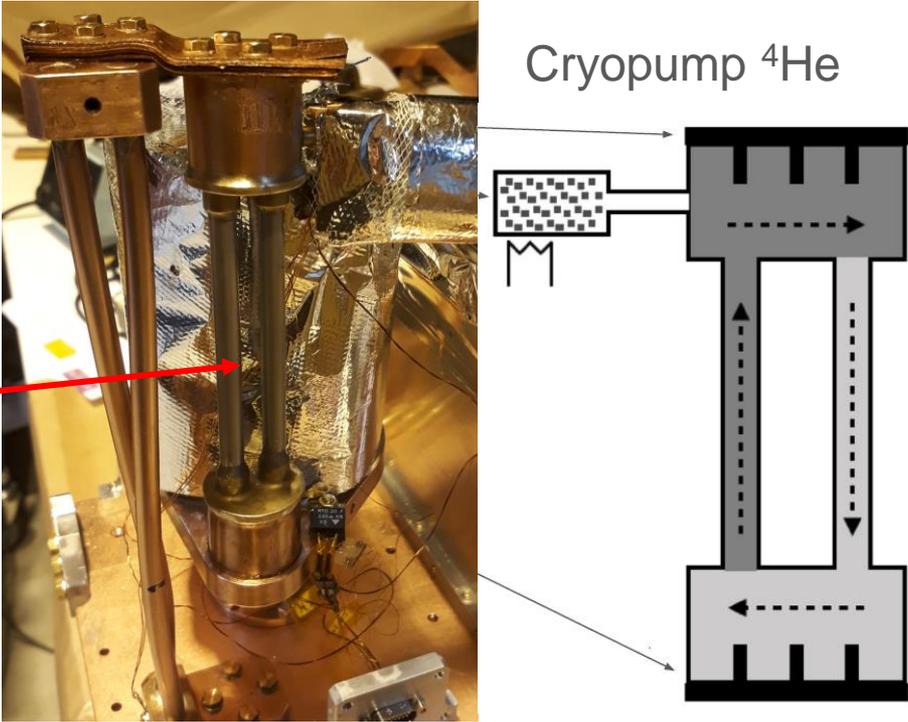
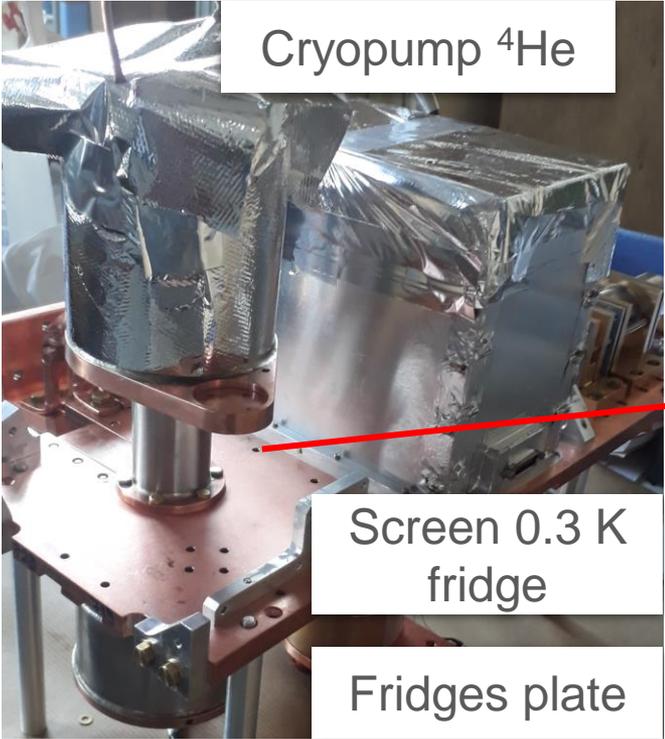
- Manchester university
- Thermal link 1 K stage for  $T < 4$  K
- Used by the cryopumps 1 K and 0.3 K

Fridge plate:

- Connected to the PT2 head
- $T = 3$  K



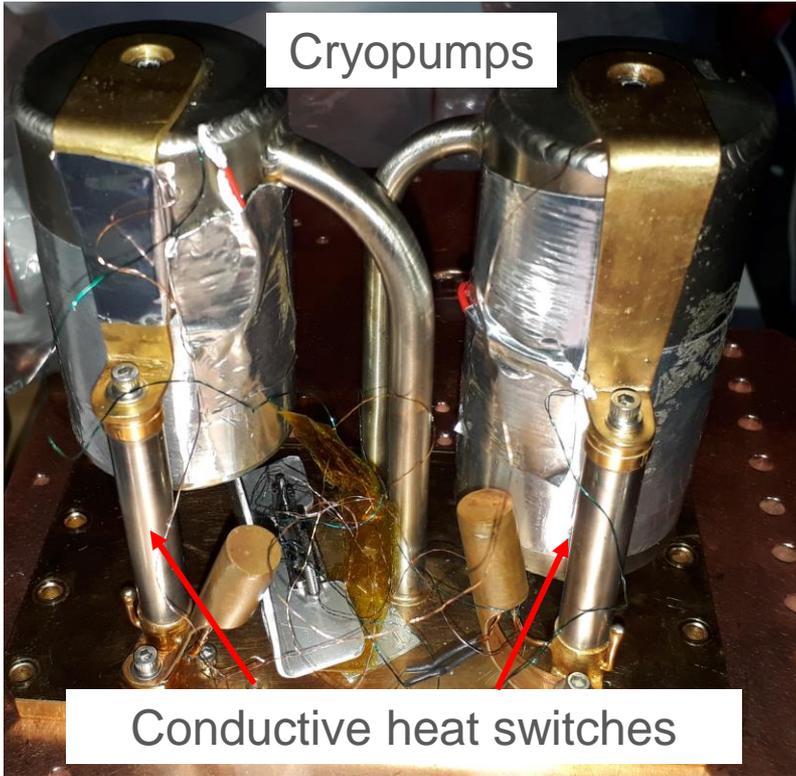
# QUBIC cryogenics: 1 K fridge



1 K evaporator

Convective heat switches 40 mW/K

# QUBIC cryogenics: 0.3 K fridge

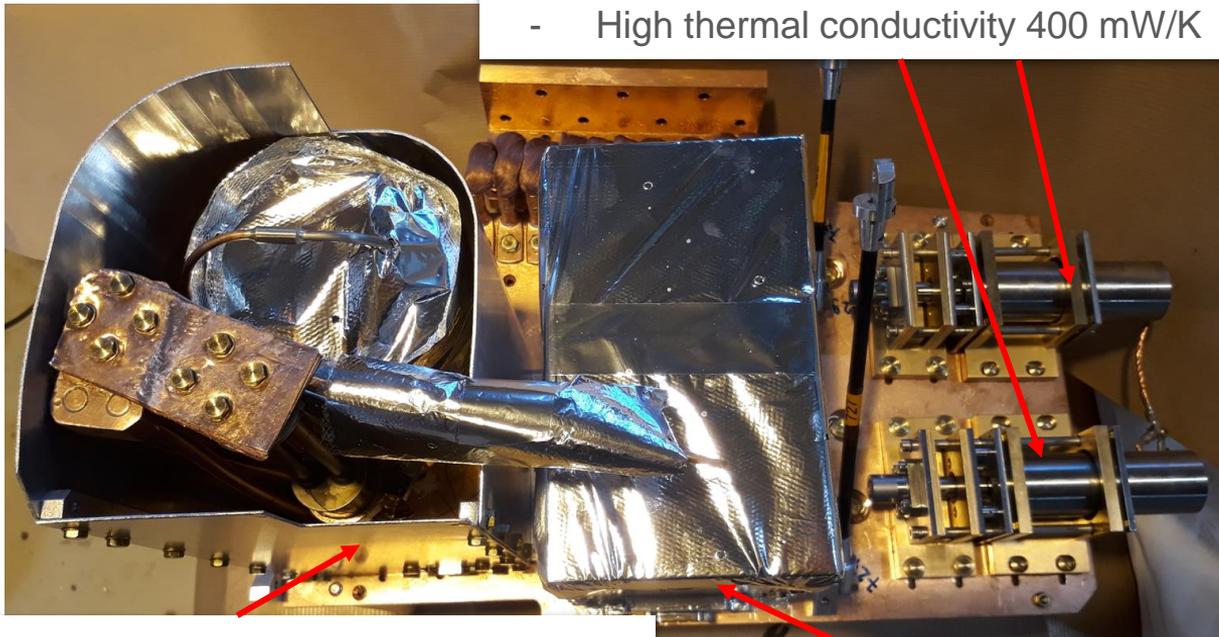


Concentric evaporators

# QUBIC cryogenics: assembled fridge plate

Mechanical heat switches:

- Closed from 300 K to 4 K
- High thermal conductivity 400 mW/K

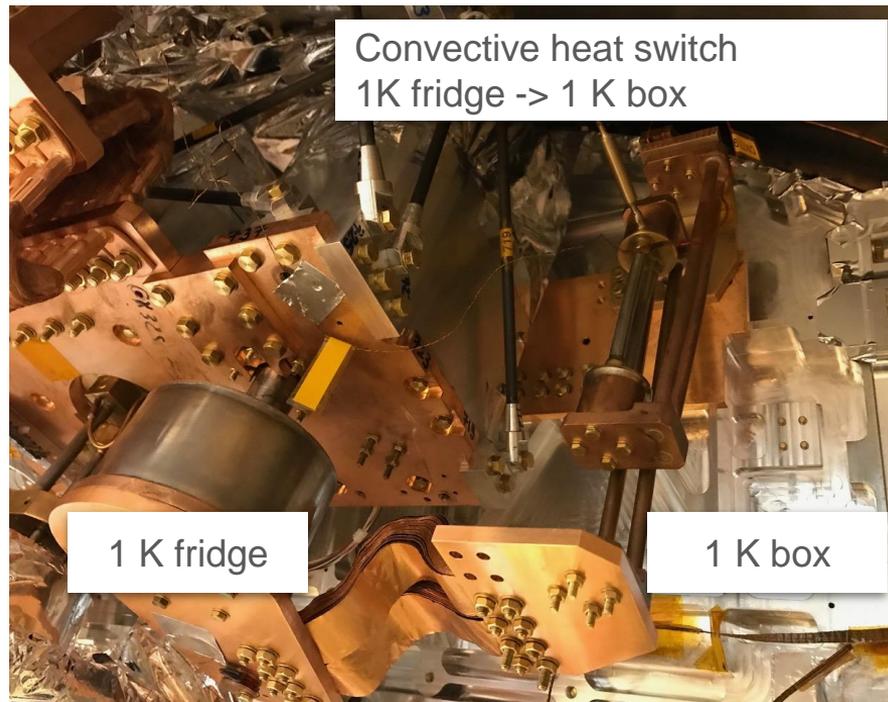
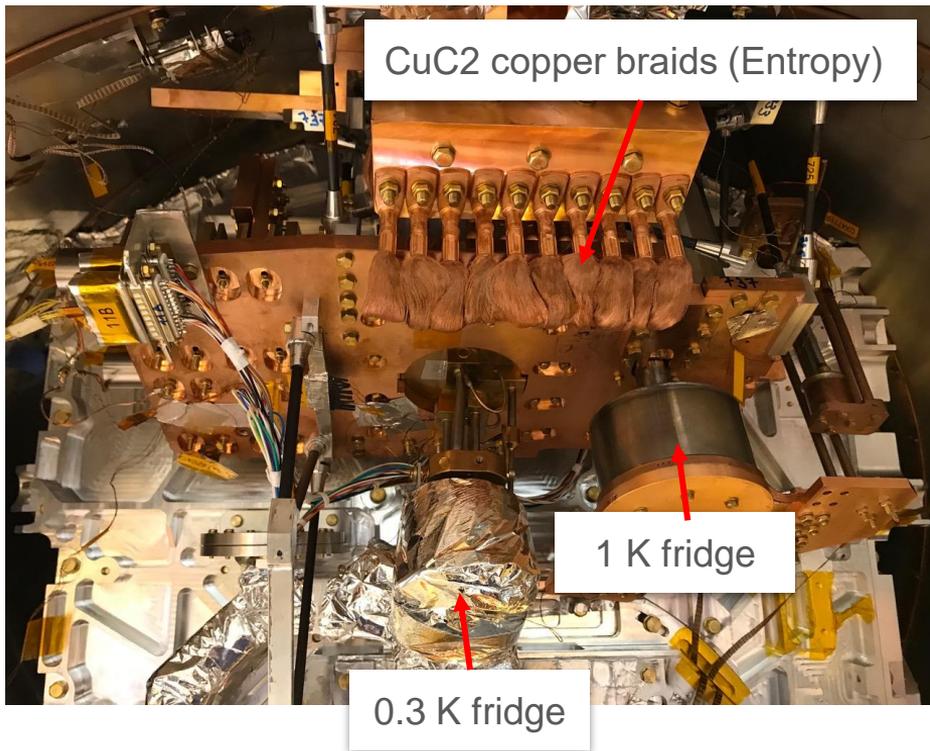


Thermal screen 1 K fridge cryopump

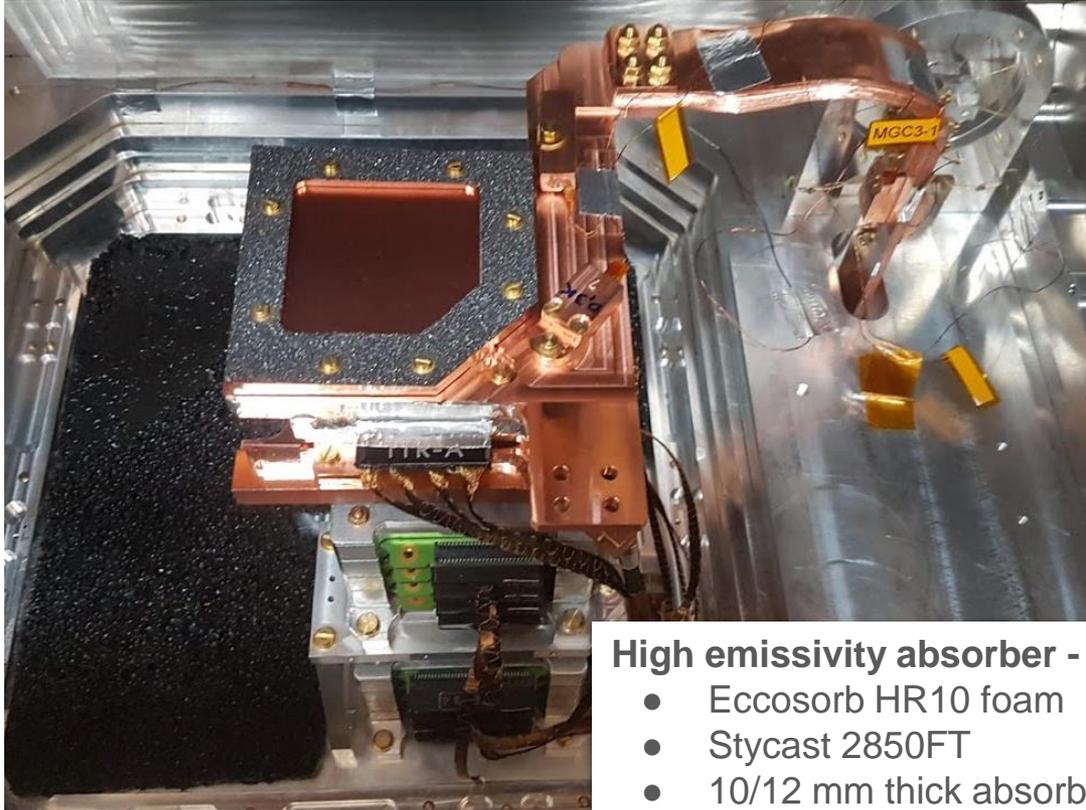
Thermal screen 0.3 K fridge cryopump



# QUBIC cryogenics: assembled fridge plate



# QUBIC cryogenics: $\frac{1}{4}$ focal plane + cold stop

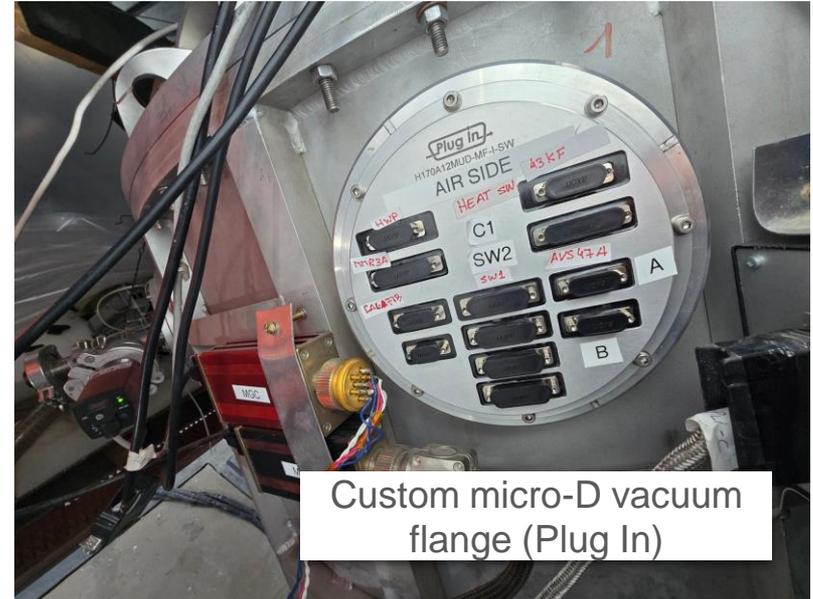


**High emissivity absorber - anti reflection mm**

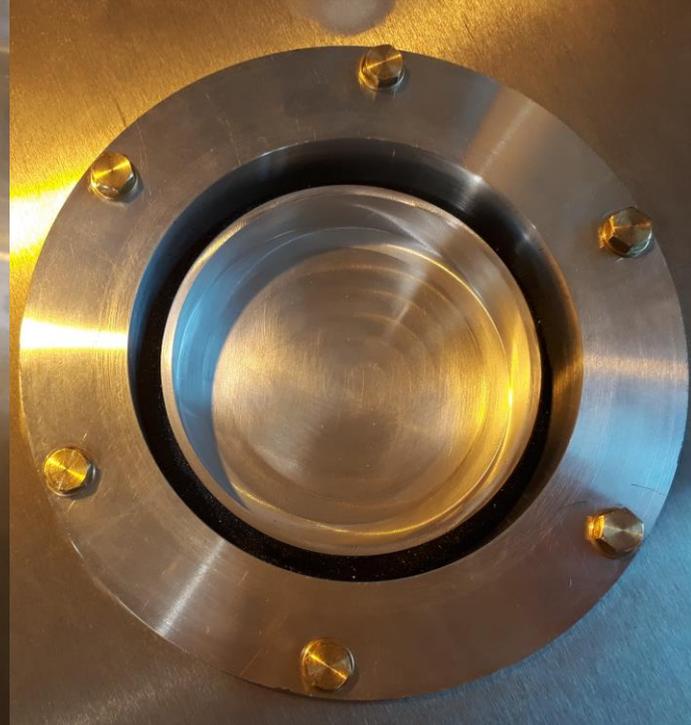
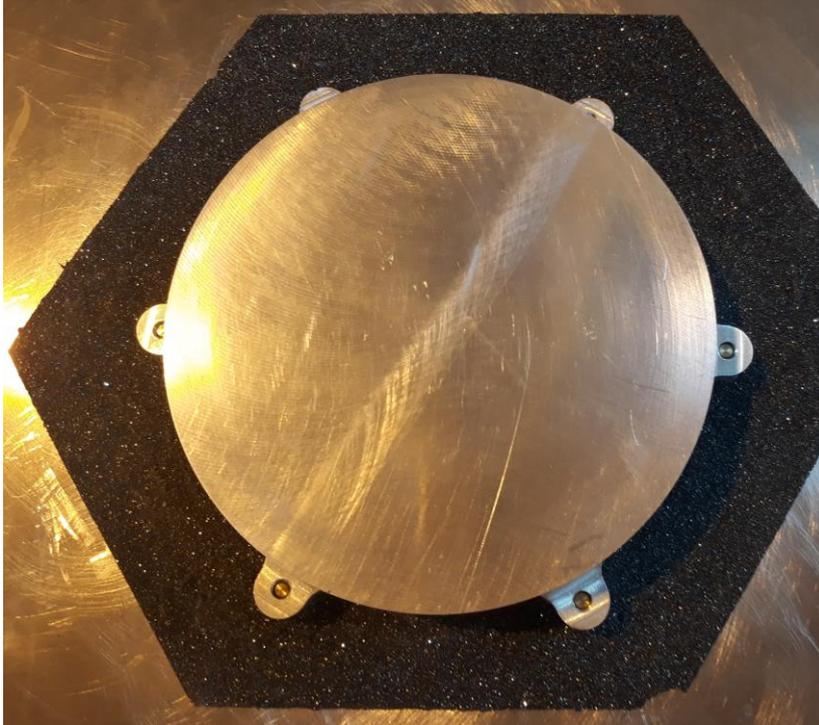
- Eccosorb HR10 foam
- Stycast 2850FT
- 10/12 mm thick absorber

# QUBIC vacuum

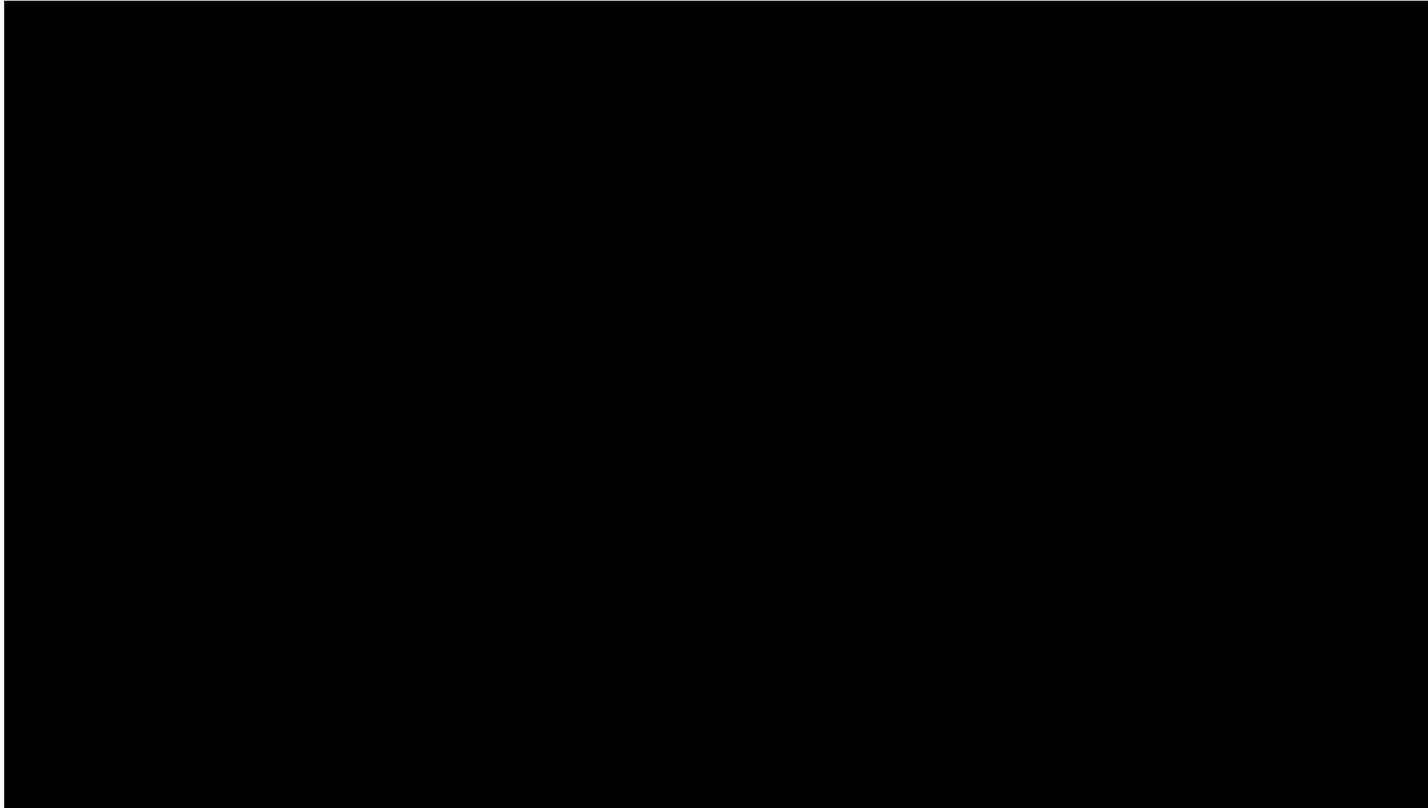
Simple and conventional vacuum system.



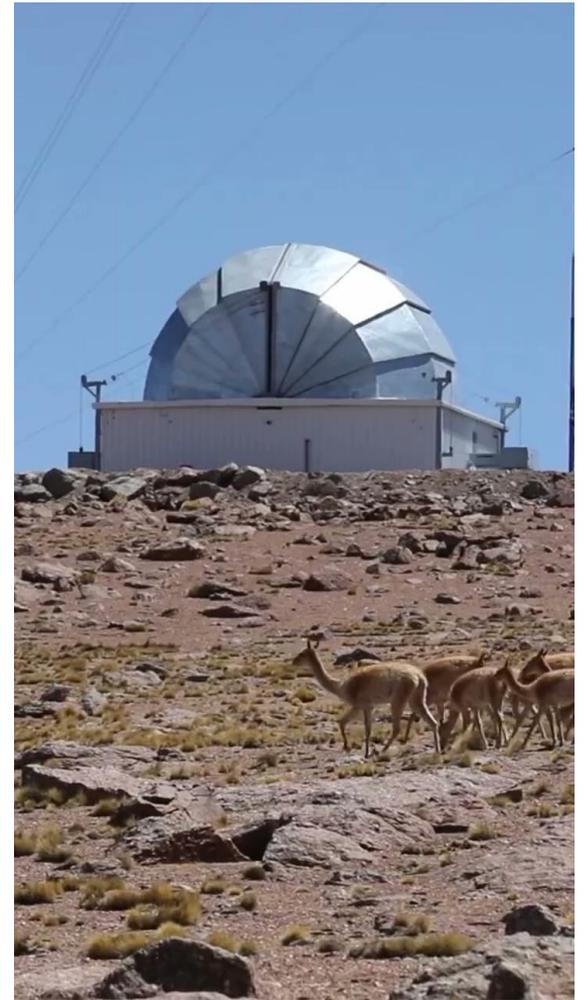
# QUBIC vacuum: 1 K box pumping baffle + absorber



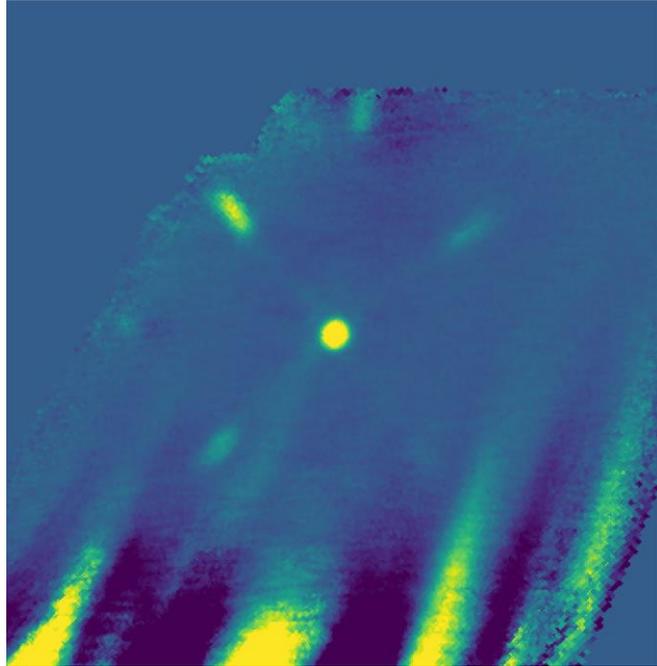
# QUBIC site



# QUBIC commissioning



# QUBIC first results



# QUBIC next steps

- Installation of the calibration source
  - Synthesized beam mapping
  - Time constant measurements
  - Beginning of Self-Calibration (long term effort)
  - Polarization calibration with HWP modulation
- Installation of the Cable Carrier
  - Full scan of the synthesized beam
  - Sky scans:
    - Moon
    - Galactic Plane and sources
    - CMB
- Early 2026 (TBC): implementation of Ultra-Wide-Band
  - Filters were ordered from Celtic THz Technology (Cardiff) by APC
  - UWB validation until late 2026 (then upgrade to FI)

## QUBIC integration at APC

