

“Magnetic Metallic Calorimeters: Micromachined Absorbers for CMB detection”.



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Karlsruhe Institute of Technology, ALEMANIA





Motivation: QUBIC

- 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 Astroparticulas, Argentina
- Instituto Argentino de Radioastronomía, Argentina

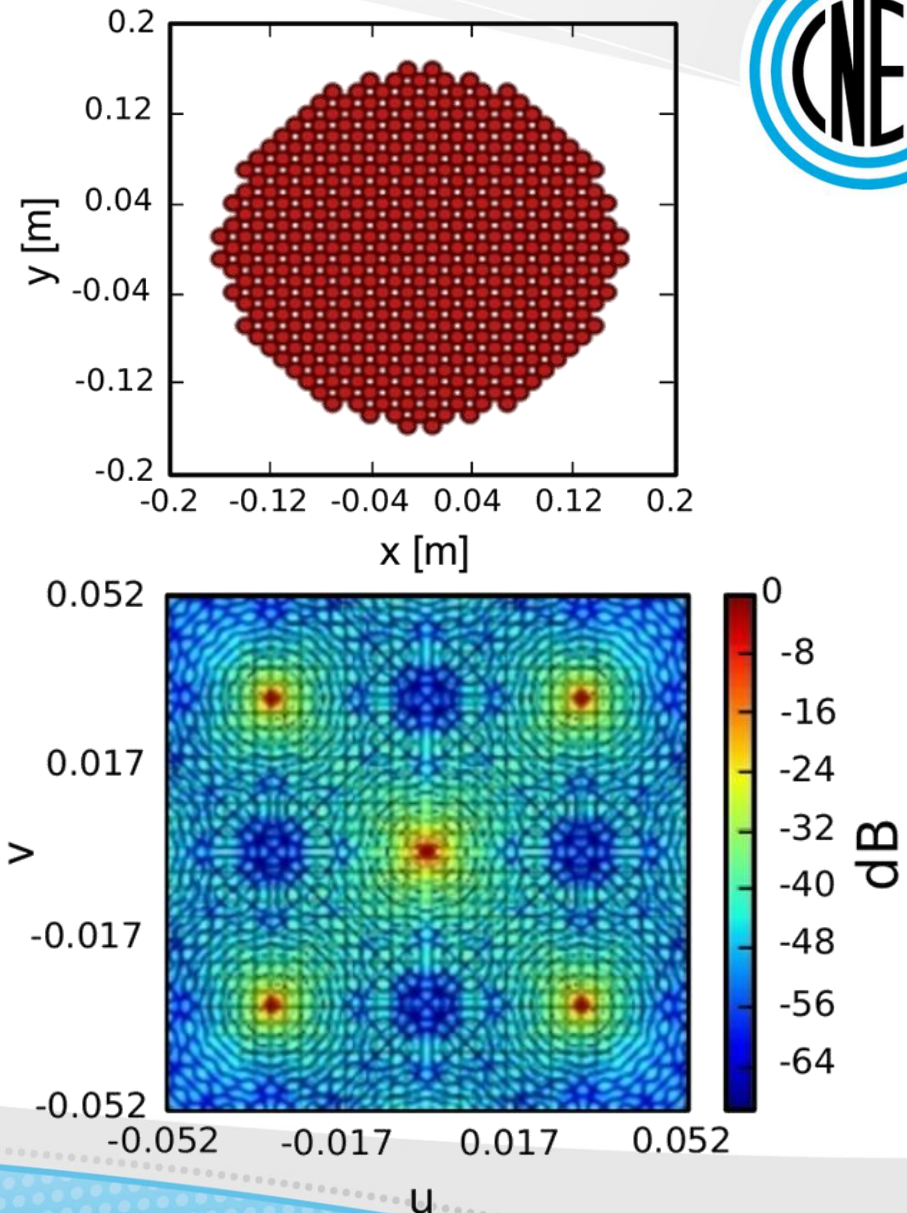
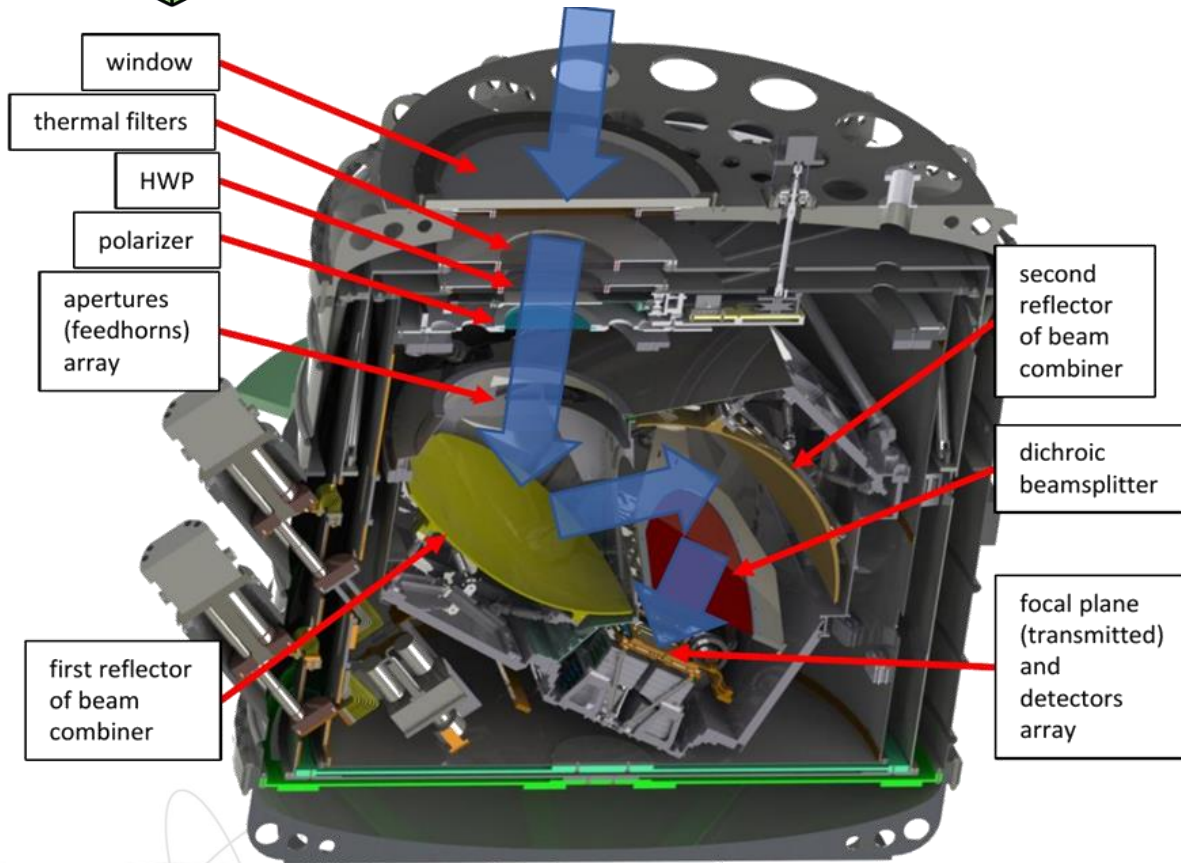
130 Collaborators
22 laboratories
6 countries

+SISSA joined



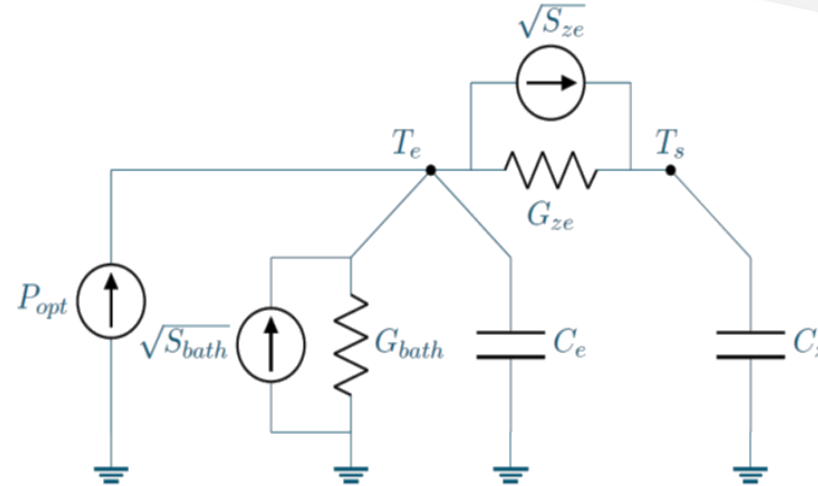
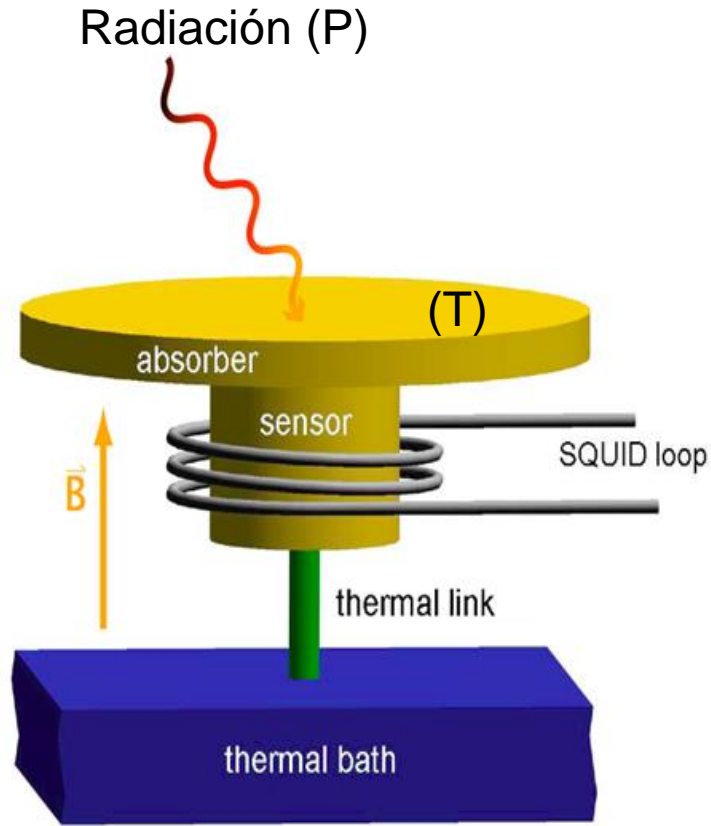


Motivation : QUBIC



- Bolometric Interferometer
 - Extreme sensibility with TESs \rightarrow MMBs
 - Low Systematics due to interferometrics
 - Self Calibration and spectroscopic analysis

MAGNETIC Micro BOLOMETERS, MMBs

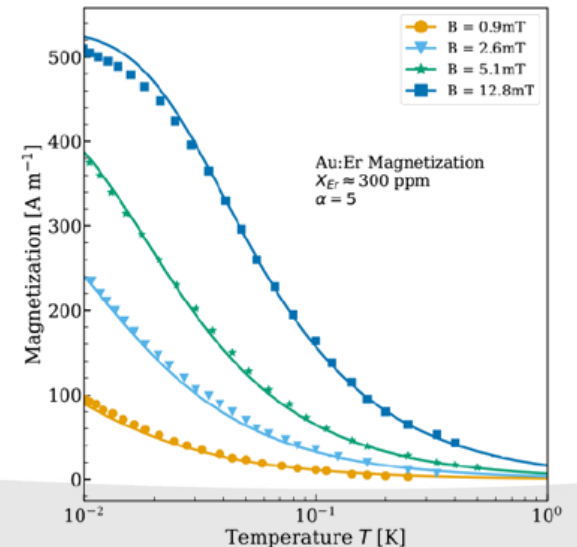


$$\frac{\partial T}{\partial P} = \frac{1}{G_{bath}} \cdot \frac{1}{\frac{C_e + C_z}{G_{bath} G_{ze}} \cdot S^2 + \frac{C_z(G_{bath} + G_{ze}) + C_e G_{ze}}{G_{bath} G_{ze}} \cdot S + 1}$$

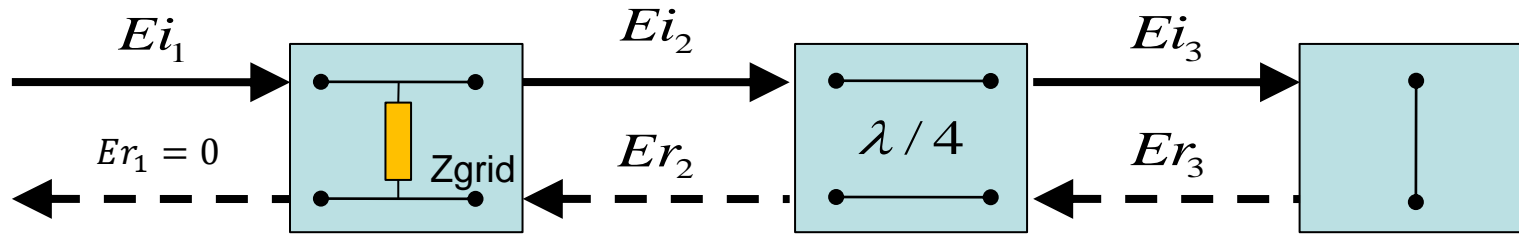
$$\frac{\partial \Phi}{\partial T} = \sum \frac{|\vec{B}(\vec{r})|}{I_{field}} \cdot \frac{\partial M}{\partial T} \Big|_{|\vec{B}(\vec{r})|} \cdot \Delta V$$

$$\frac{\partial \Phi_{sq}}{\partial \Phi} = \frac{k \sqrt{L_{in} L_s}}{L_m + L_{stray} + L_{in}}$$

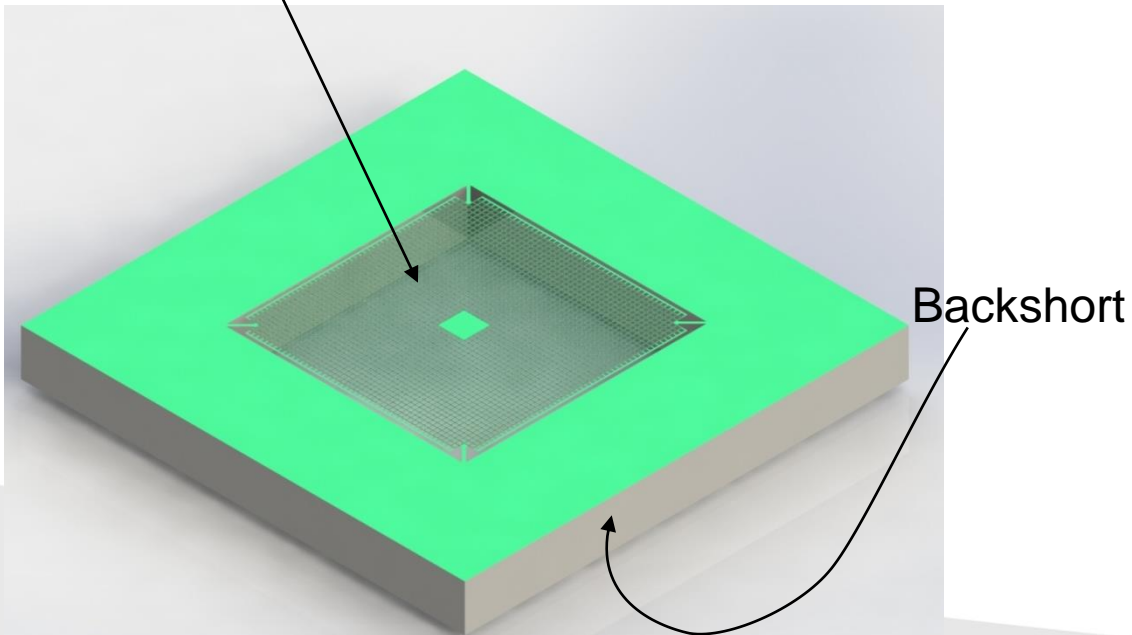
$$\mathcal{R}_{MMB} = \frac{\partial \Phi_S}{\partial P} = \frac{\partial T}{\partial P} \frac{\partial \Phi}{\partial T} \frac{\partial \Phi_S}{\partial \Phi}$$



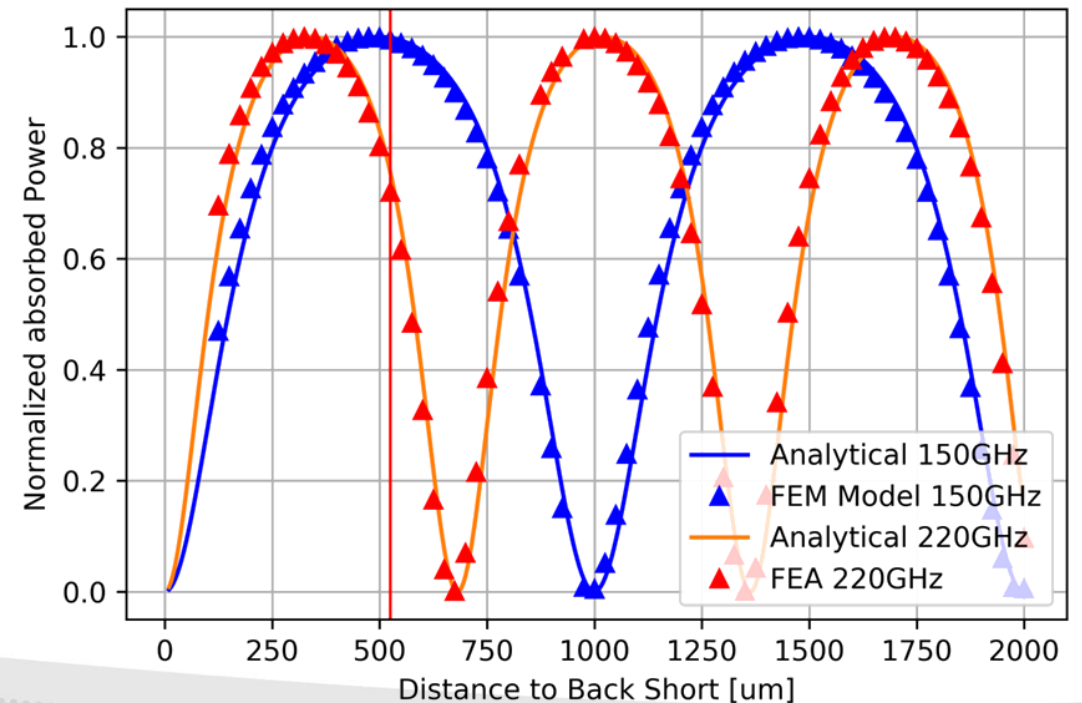
MMBs: Coupling to CMB



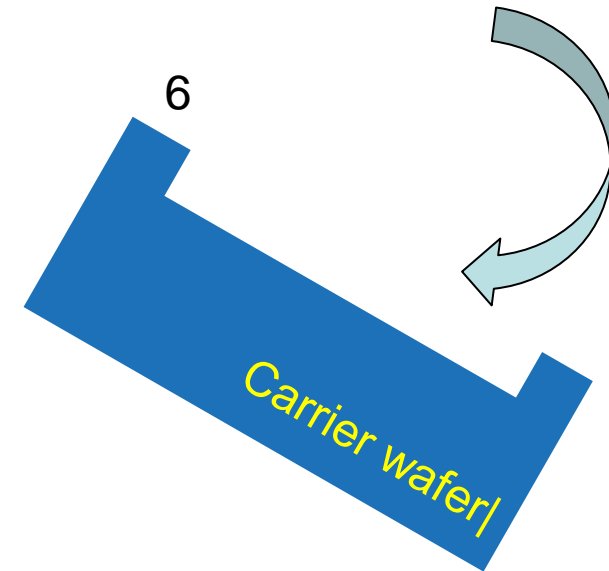
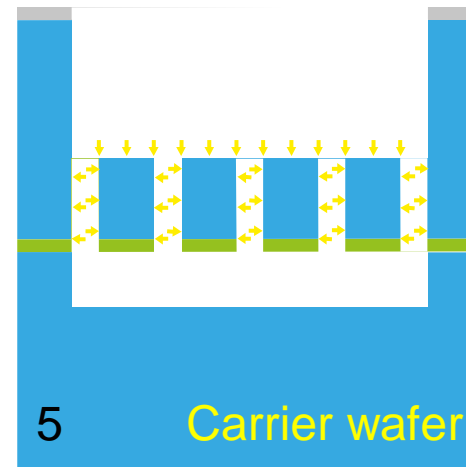
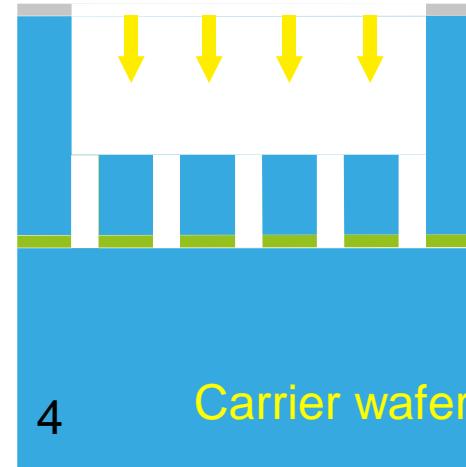
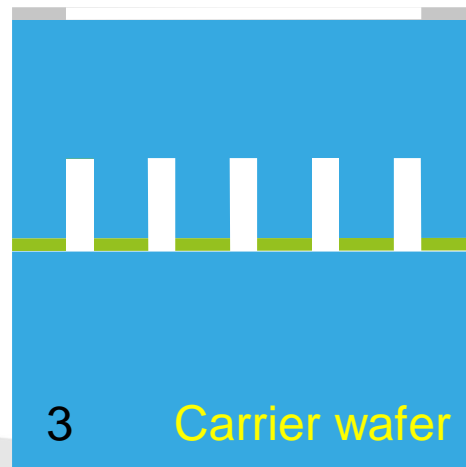
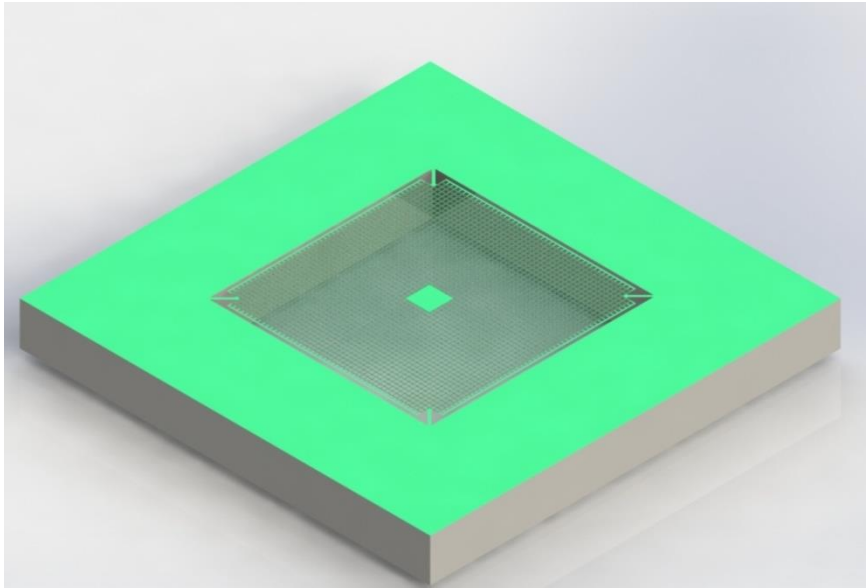
Absorbing grid, Zgrid



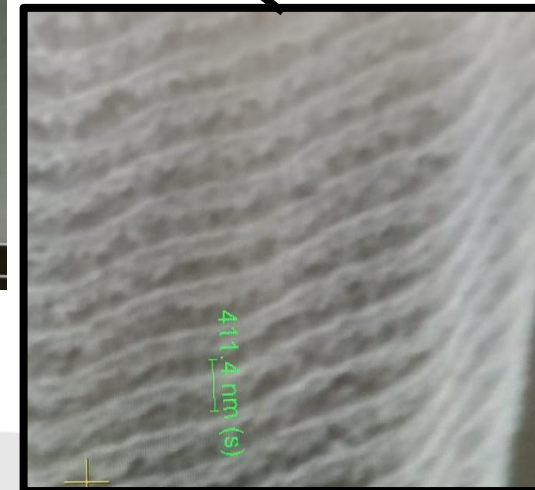
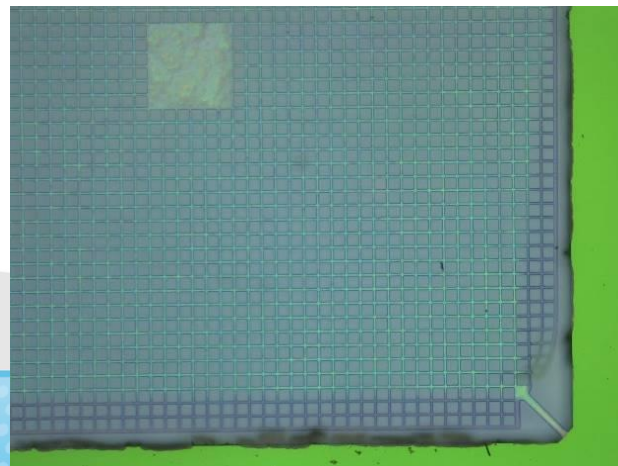
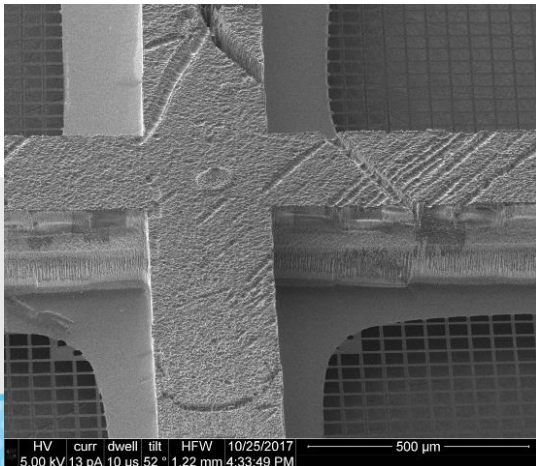
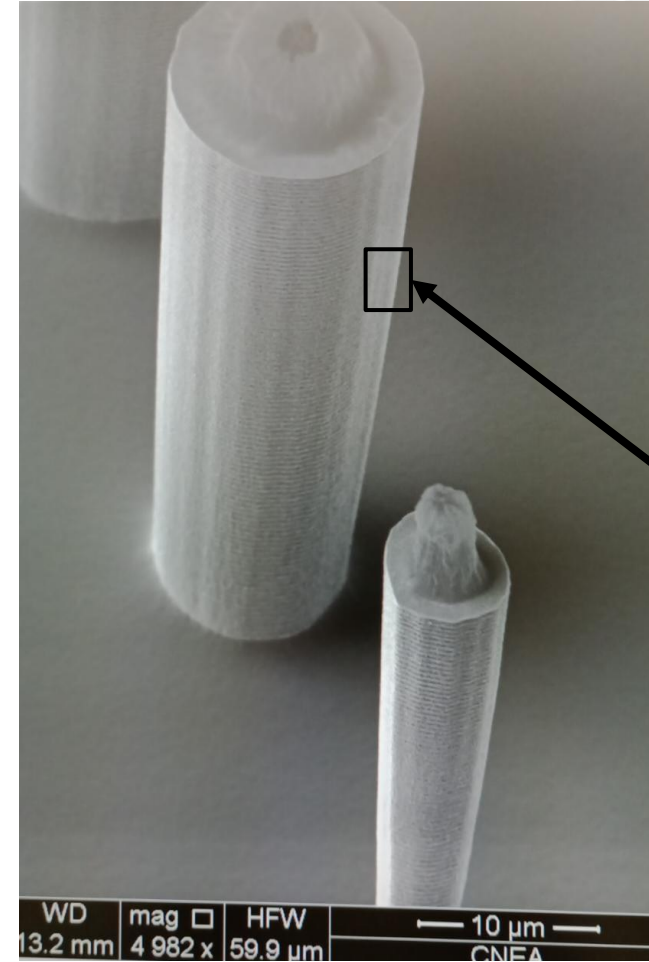
Absorción de energía incidente



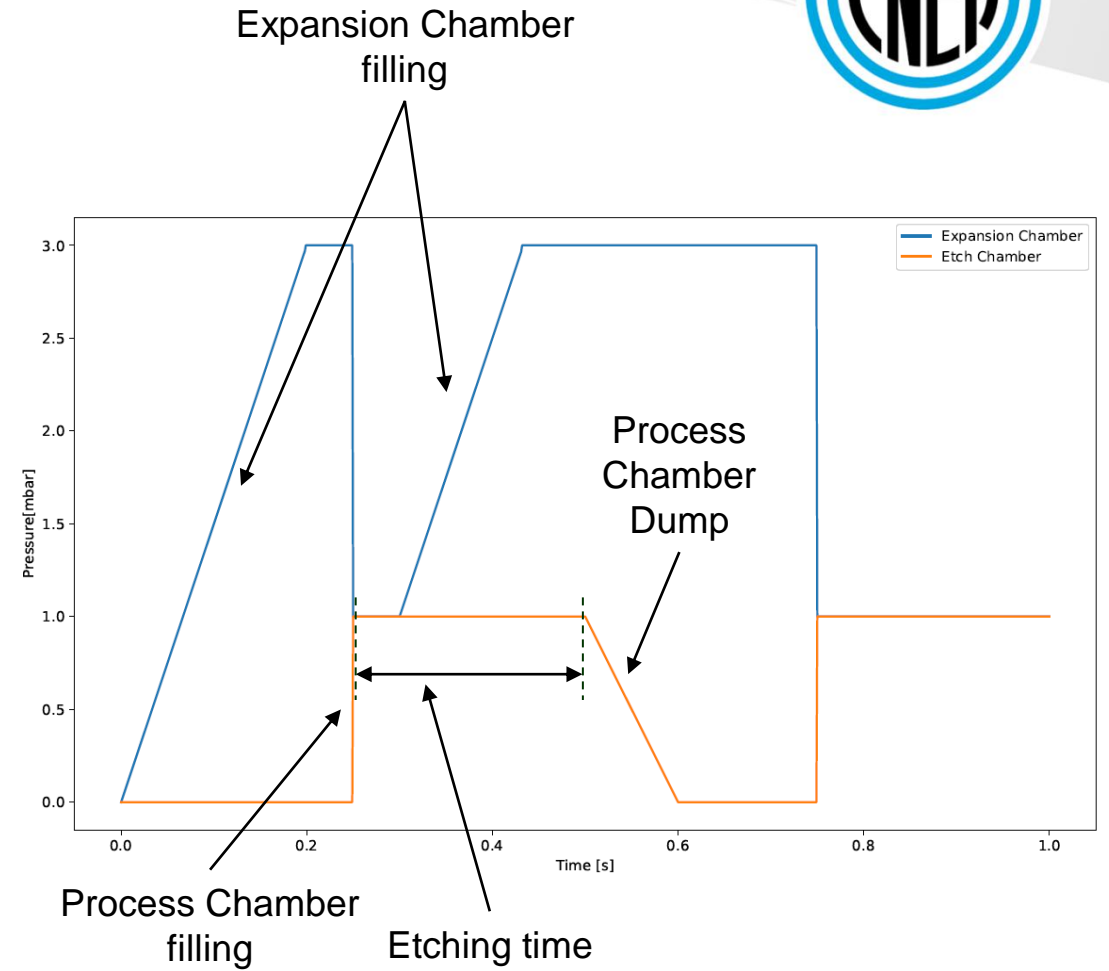
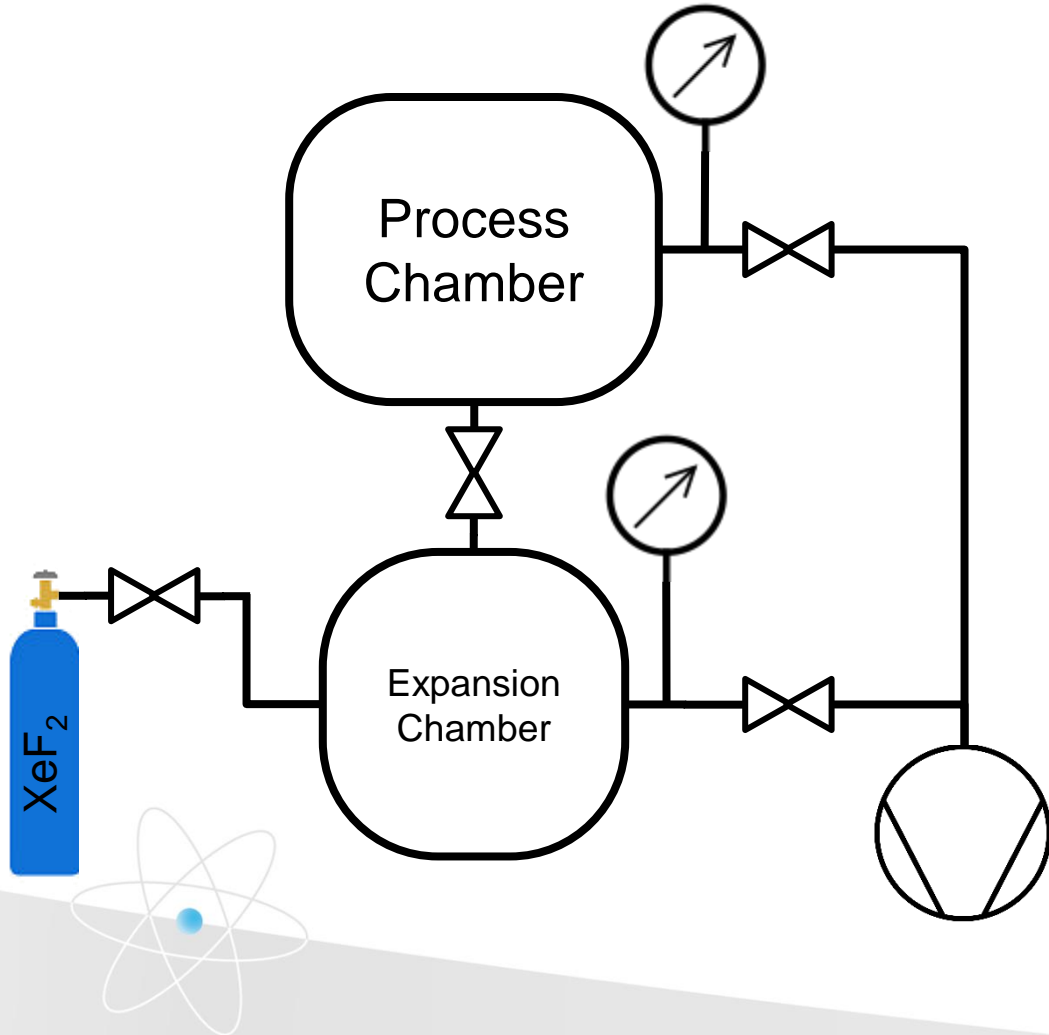
Microfabrication I: Release process



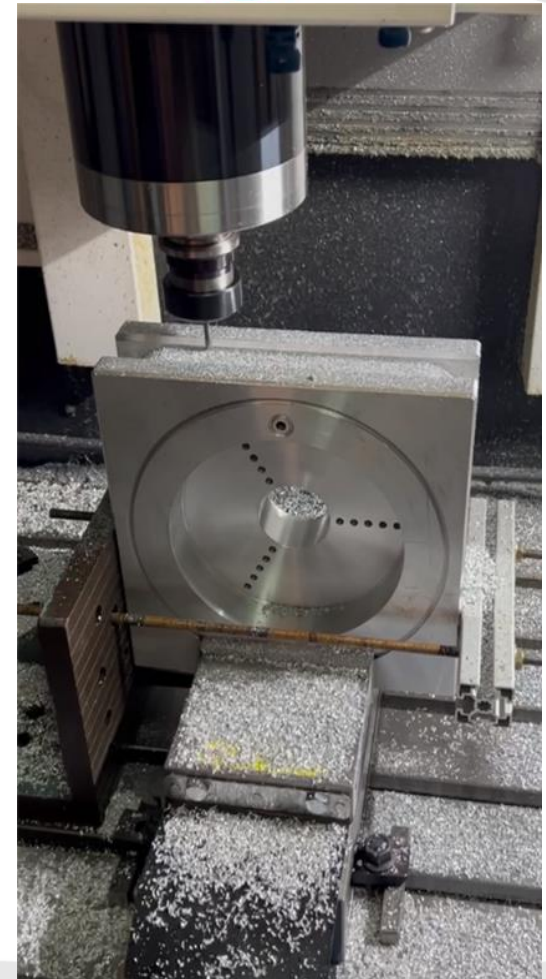
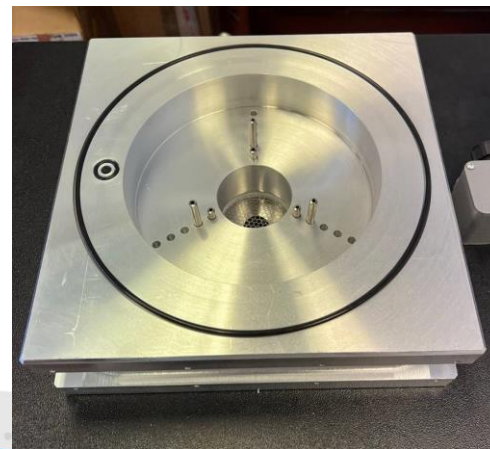
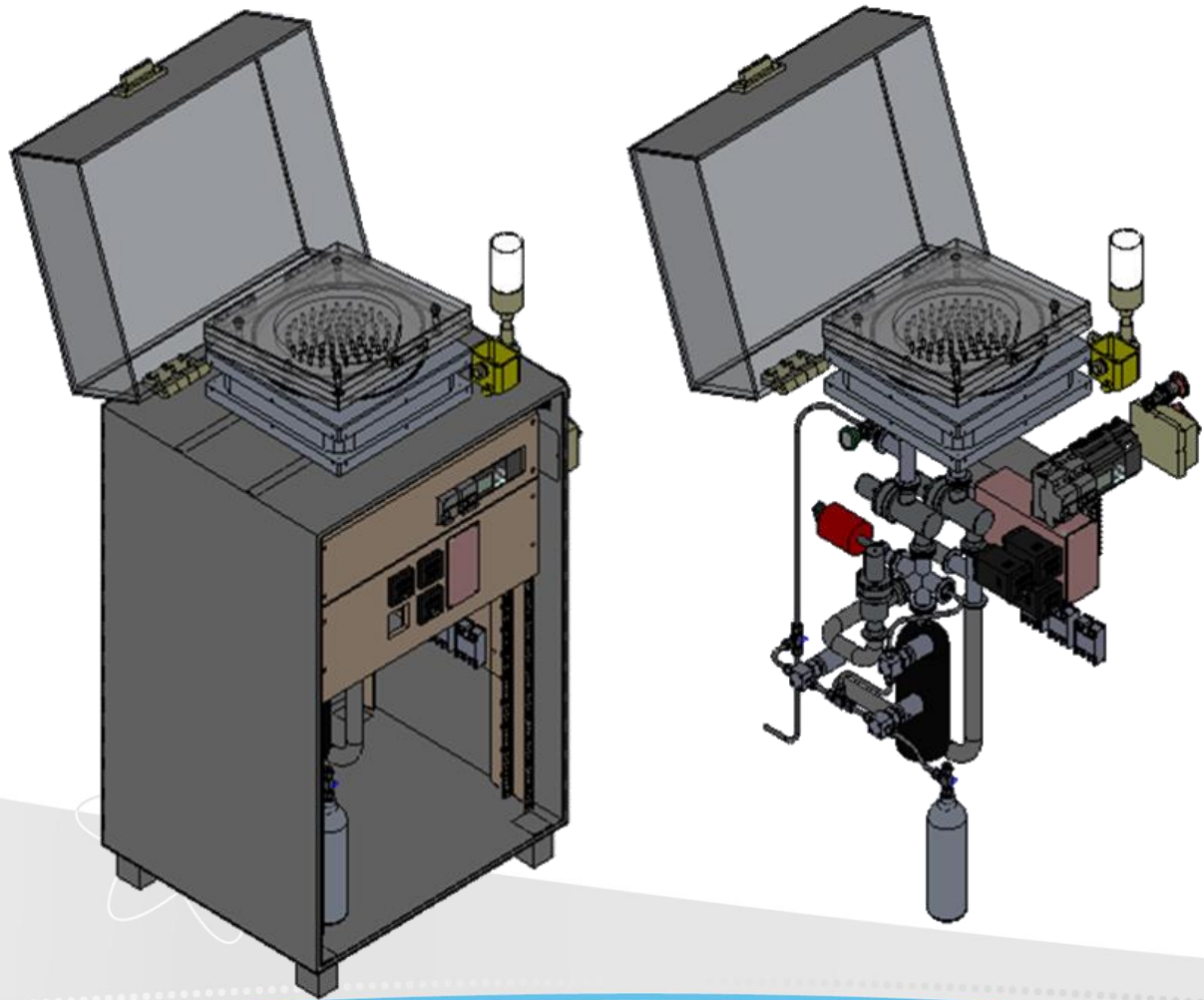
Microfabrication II: Release process



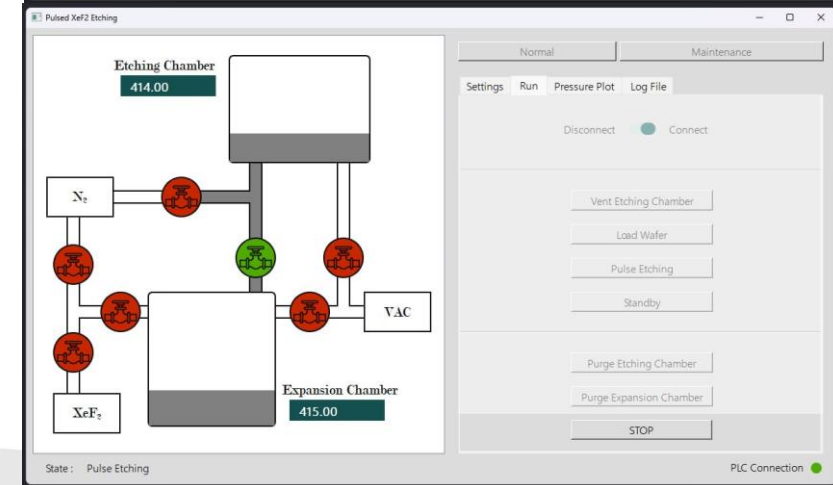
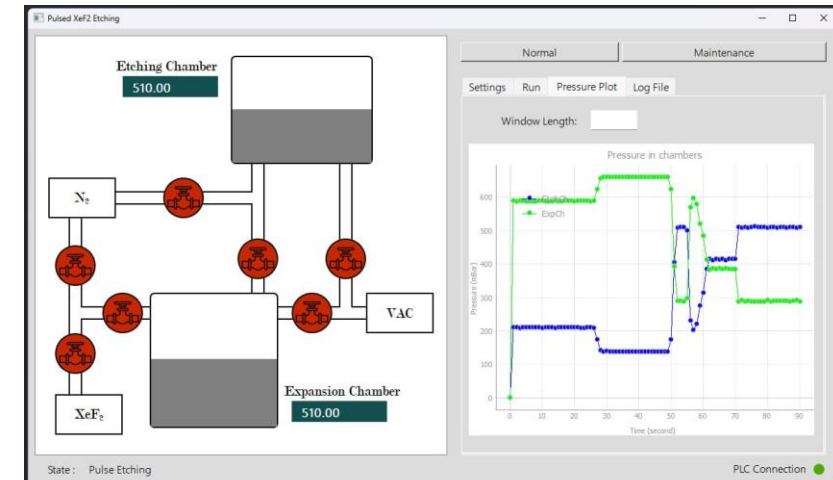
Microfabrication III: XeF₂



Microfabrication IV: XeF₂

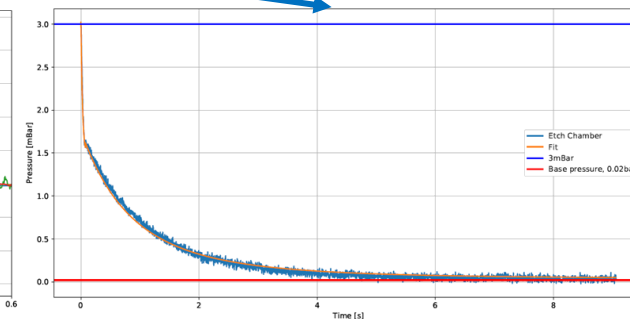
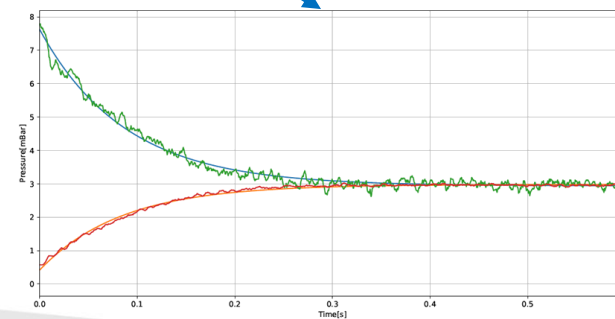
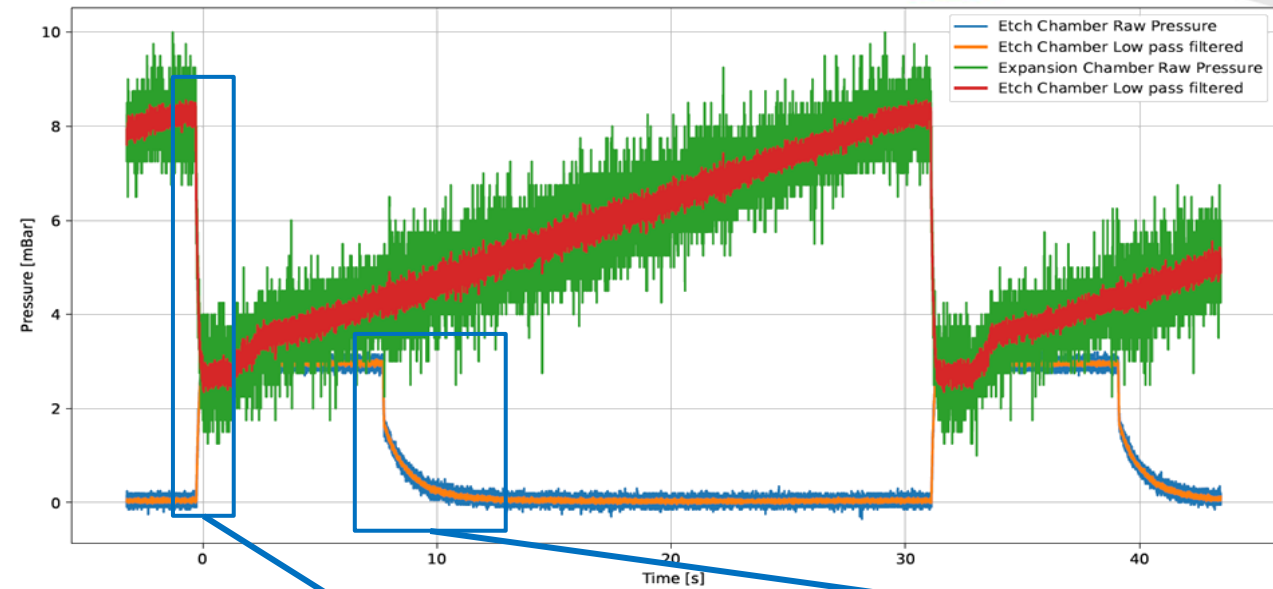


Microfabrication V: XeF₂



Software: Lucía Sucunza

Microfabrication VI: XeF₂



Llenado de la cámara 114ms

Vaciado de la cámara 2,650s

EQUIPMENT I



He3/He4 Dilution Fridge
Bluefors LD250
Arribo: Octubre 2022

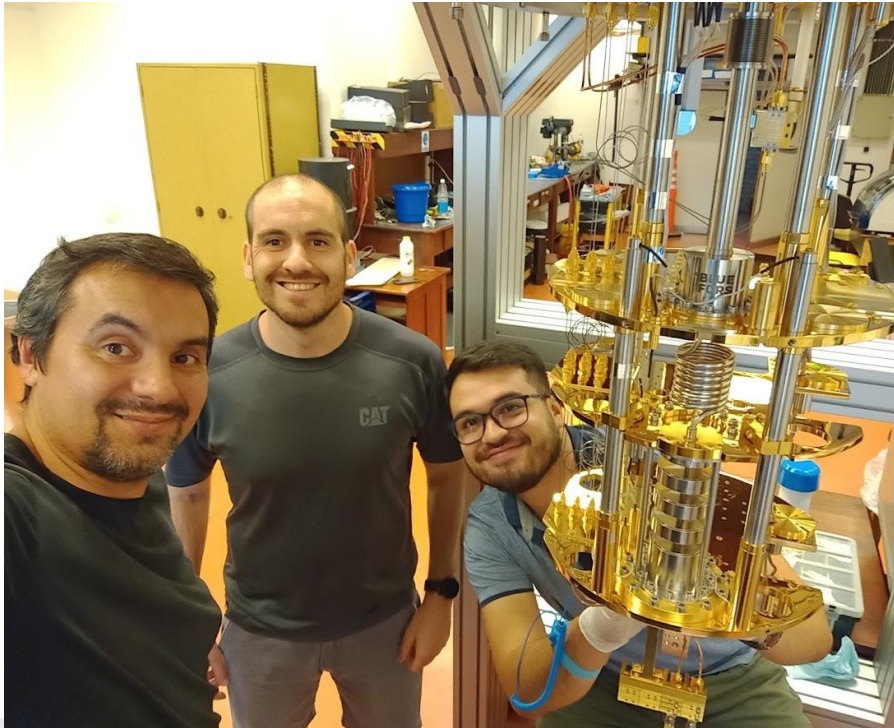


AJA ATC2400 Sputter
Arribo: Marzo 2023



Keysight PNA-X
Arribo: Mayo 2022

EQUIPMENT II



He3/He4 Dilution Fridge
Bluefors LD250
Operativo desde Marzo 2023

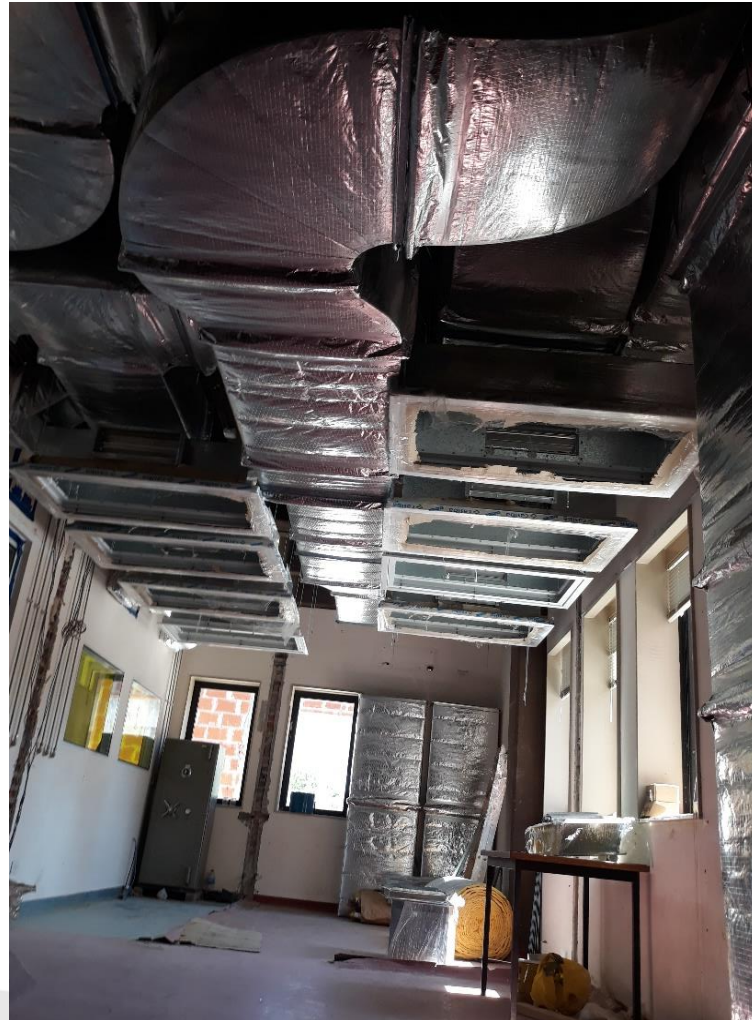


AJA ATC2400 Sputter
En proceso de ensamblado
Arribo: Octubre 2023



Keysight PNA-X
Operativo junto al criostato
desde Marzo 2023

NEW LABS, AND OLD ONES REBUMPING



Estado de avance



Courses :

Introducción a Microscopías de Barrido por Sonda, Inst. Sabato, 2022
Cosmología, ITeDA, Agosto 2022

Publications, as co-autor.

Ranitzsch, Philipp & Arnold, D. & Beyer, J. & Bockhorn, L. & Bonaparte, J. & Enss, C. & Kossert, K. & Kempf, Sina & Loidl, Martin & Mariam, Riham & Nähle, O. & Paulsen, M. & Rodrigues, Matias & Wegner, M.. (2020). MetroMMC: Electron-Capture Spectrometry with Cryogenic Calorimeters for Science and Technology. *Journal of Low Temperature Physics*. 199. 10.1007/s10909-019-02278-4.

Suitability of magnetic microbolometers based on paramagnetic temperature sensors for CMB polarization measurements

[Geria, J.M.](#), [Hampel, M.R.](#), [Kempf, S.](#), ...[Platino, M.](#), [Etchegoyen, A.](#)

Journal of Astronomical Telescopes, Instruments, and Systems, 2023, 9(1), pp. 16002

An implementation of a channelizer based on a Goertzel Filter Bank for the read-out of cryogenic sensors

[Ferreyro, L.](#), [García Redondo, M.](#), [Hampel, M.](#), ...[Weber, M.](#), [Etchegoyen, A.](#)

Journal of Instrumentation, 2023, 18(6), P06009

Aliasing Effect on Flux Ramp Demodulation: Nonlinearity in the Microwave Squid Multiplexer

[Salum, J.M.](#), [Muscheid, T.](#), [Fuster, A.](#), ...[Sander, O.](#), [Weber, M.](#)

Journal of Low Temperature Physics, 2023 (En Prensa)

Estado de avance



Presentaciones a congresos.

20th International Conference on Low Temperature Detectors, Daejeon, Korea. Julio 2023

**MICROFABRICATION PROCESS TOWARDS
MAGNETIC MICROBOLOMETERS**

Juan J. Bonaparte^{1,2,3,4,5}, Nahuel Müller¹, Enrico Petrella¹, Luciano P. Ferreyro¹, Juan M. Salum^{1,5}, Manuel E. García Redondo¹, Jesús D. Bonilla Neira², Matias R. Hampel¹, Alejandro Almela¹, Sebastian Kempf¹, Mariano Gómez Benso¹, Manuel Piazini¹, Marc Weber¹, Alberto Etchegoyen¹

¹Instituto de Nanociencias y Nanotecnología, Comisión Nacional de Energía Atómica (CNEA), Argentina, ²Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Argentina, ³Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina, ⁴Institut für Mikro- und Nanoelektronische Systeme, Karlsruhe Institute of Technology (KIT), Germany, ⁵Nationale Institute of Technology (KIT), Germany

Motivation

- ✓ Quest for B-Modes is a major challenge in modern cosmology.
- ✓ CMB survey recently deployed in northern Argentina.
- ✓ New application of Magnetic-Metallic sensors.
- ✓ Fully superconducting design, suitable to SQUID readout.
- ✓ Broad and smooth temperature dependence allowing straightforward calibration.

Magnetic Microbolometer (MMB)

Canonical ensemble modeling

Monte Carlo simulations Au-Er sensor

MicroFabrication Facilities

150m² open facility located in Buenos Aires, Argentina

Optical Lithography, RIE, DeepRIE and XeF₂ dry etching, SiO₂ and LowStress SiN₂ PECVD, Dedicated Superconducting materials Sputtering, SEM/FIB inspection, Optical and stylus profiling

Proposed microfab process

- a. Two level Nb wiring with PECVD SiO₂ intermetallic isolation.
- b. Au-Er sputter lift-off.
- c. Suspended membrane Fluorine based RIE definition.
- d. Device layer frontside RIE etch.
- e. Backside Al/hardmask deposition and patterning.
- f. Backside deep RIE up to box and box removal.
- g. Final XeF₂ etch to release suspended membrane

RFSoc Gen3-Based Software-Defined Radio Characterization for the Readout System of Low-Temperature Bolometers.

M. E. García Redondo^{1,2,3,4,5}, T. Muschheid¹, R. Garmann¹, J. M. Salum^{1,5}, L. P. Ferreyro^{1,2,3,4,5}, N. A. Müller^{1,2,3,4,5}, J. D. Bonilla-Neira^{1,2,3,4,5}, J. M. Geria^{1,2,3,4,5}, J. J. Bonaparte^{1,2,3,4,5}, D. A. Almela^{1,2,3,4,5}, L. E. Ardlia-Perez¹, M. R. Hampel^{1,2,3,4,5}, A. E. Fuster^{1,2,3,4,5}, M. Piazini^{1,2,3,4,5}, O. Sander^{1,2,3,4,5}, M. Weber¹, A. Etchegoyen¹

¹Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Argentina, ²Karlsruhe Institute of Technology (KIT), Germany, ³Universidad Nacional de San Martín (UNSAM), Argentina, ⁴Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina, ⁵Universidad Tecnológica Nacional (UTN), Argentina, ⁶Comisión Nacional de Energía Atómica (CNEA), Argentina.

Detection System Overview (see RP-056 Table)

- 1024 Magnetic Microbolometers (see RP-052, RP-053)
- Microwave SQUID Multiplexing (see RP-050, RP-055)
- Spacing 4 MHz and 200 kHz bandwidth
- Operation band between 4 and 8 GHz
- RFSoc Gen3-Based SDR readout system.

RFSoc Gen3-Based SDR Readout System Hardware components

- ZCU102 evaluation kit (x16 DACs and x16 ADCs).
- Clock board CLK104.
- Multi-Band RF Mixing board (R-L-E Muschheid's Tail)
- Five 800 MHz complex sub-bands.
- Signal conditioning and Monitoring.
- Flux-Ramp generation board.

Firmware configuration

- RFDCC core configuration.
- 20k DAC sampling at 1 Gsps in dual real Complex-to-Complex
- Coarse and fine channelization.
- 128 channels Polyphase filter bank.
- Four 1024-Multichannel DDCs.

RF Performance Characterization Set-Up

- Single band characterization.
- 800 MHz band centered at 7.5 GHz.
- Conditions emulating real μ MUX readout.
- Simulation characterization.
- 200 tones randomly spaced, 4 MHz mean spacing, 200 kHz standard deviation.
- 40-dBm tone power in Tx output.
- IQ and slope calibrated.
- RF Loop-back characterization.
- 40-dBFS x ADCs input.
- Possible SQUID frequencies for bolometric applications (see RP-079).

Stimulation Measurements

- Tx output connected to phase noise analyzer.
- Phase/Amplitude noise measured at several tone frequencies.
- Comparison with cryo-LNA noise.

RF Loop-back Measurements

- Tx-Rx coaxial cable loop emulating delay and attenuation of the cold circuit.
- Phase/Amplitude noise measured after fine channelization.

Conclusions and Future Work

- Demonstrated performance compatible with the state-of-the-art SDR readout systems (<100 dBc/Hz).
- Easy deployment and high integration level achieved at low cost.
- RFDCC and CLK configuration successfully integrated to our VIOCCO based build system.
- Reduction of RF non-linearities and phase/amplitude noise.
- Open-loop gain and system noise measurements with μ MUX.
- Firmware optimization for bolometric applications (see RP-079).
- RFDCC and CLK configuration successfully integrated to our VIOCCO based build system.

Goertzel Filter Bank Channelizer for Cryogenic Sensors Read-Out

L. P. Ferreyro^{1,2,3,4,5}, J. M. Salum^{1,5}, M. García Redondo^{1,2,3,4,5}, T. Muschheid¹, M. R. Hampel^{1,2,3,4,5}, D. A. Almela^{1,2,3,4,5}, A. Fuster^{1,2,3,4,5}, J. M. Geria^{1,2,3,4,5}, R. Garmann¹, J. Bonaparte^{1,2,3,4,5}, J. Bonilla-Neira^{1,2,3,4,5}, L. E. Ardlia-Perez¹, N. Müller^{1,2,3,4,5}, O. Sander^{1,2,3,4,5}, A. Etchegoyen¹, M. Weber¹

¹Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Argentina, ²Consejo Nacional de Investigaciones Científicas (CONICET), Argentina, ³Universidad nacional de San Martín (UNSAM), Argentina, ⁴Instituto de Micro- y Nanoelectrónica (IMS), Karlsruhe Institute of Technology (KIT), Germany, ⁵Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT), Germany, ⁶Universidad Tecnológica Nacional (UTN), Argentina, ⁷Comisión Nacional de Energía Atómica (CNEA), Argentina, ⁸Karlsruhe Institute of Technology (KIT), Germany

1. Motivation

- Target a warm read-out electronics capable of reading thousands of channels (at reasonable costs).
- Dispose of a highly configurable and versatile warm read-out electronics.
- Improve the relationship between the acquired data and the information contained in it, in cryogenic sensors applications in calorimetric and bolometric experiments; direct impact in the throughput.

2. Implementation details

- Discrete Fourier Transform based method, attempting individual single-toner monitoring for reading several number of cryogenic sensors at once.

3. Experimental Setup

- LD250 Bluewin refrigerator (PID controlled at 320 mK).
- LNA: One - 8 GHz.
- μ MUX supplied by Prof. S. Kempf from IMS.
- Backend: Xilinx ZCU102 + AD-FMCDQAQZBZ.
- Multi-band RF Mixing board (five 800 MHz complex sub-bands and signal conditioning/monitoring) (R-L-E Muschheid's Tail)

4. Channelizer features

- Controlled spectral leakage thanks to the configurable window function to be used in the signal processing pipeline (DFT feature), by software.
- More than 80 dB of channel isolation (high crystalline isolation)

5. Microwave SQUID Multiplexer read-out

- Acquired data with a VNA-PNA-X Network Analyzer N9242B, with an IF BW of 600 kHz (compatible with GFB used window size).
- VNA - S1₁₁ - f_c - Q₁ - 4745.52, L: 4.47985 GHz, S_{11, min} - 13.268 dB.
- GFB + S1₁₁ - f_c - Q₁ - 4777.56, L: 4.47983 GHz, S_{11, min} - 13.423 dB.

6. Conclusions

- Up to ~80 dB of SNR (dominated by DDC stage).
- High Coaxial isolation (window type and size dependent).
- Low FPGA resources usage (within the state of the art).
- Highly flexible design: DDCs and GFB can be placed almost at any part of the input spectrum.
- Noise Spectral Density at the GFB output of ~ -137 dBc/Hz (mainly dominated by the DDC quantization).
- Highly flexible design: DDCs and GFB can be placed almost at any part of the input spectrum.

**The Magnetic Microbolometer detection chain:
A Detection system for QUBIC to observe the B modes of the Cosmic Microwave Background**

M. Piazini^{1,2,3,4}, D. A. Almela^{1,2,3,4}, L. E. Ardlia-Perez^{1,2,3,4}, J. J. Bonaparte^{1,2,3,4}, L. P. Ferreyro^{1,2,3,4,5}, M. E. García Redondo^{1,2,3,4,5}, R. Garmann¹, J. M. Geria^{1,2,3,4,5}, M. R. Hampel^{1,2,3,4,5}, N. A. Müller^{1,2,3,4,5}, T. Muschheid¹, J. M. Salum^{1,5}, O. Sander^{1,2,3,4,5}, M. Weber¹

¹Instituto de Tecnologías en Detección y Astropartículas (ITeDA), ²Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), ³Universidad Nacional de San Martín (UNSAM), ⁴Universidad Tecnológica Nacional (UTN), ⁵Karlsruhe Institute of Technology (KIT)

QUBIC project specifications

- B-mode polarization of the Cosmic Microwave Background (CMB)
- 150 & 220 GHz bands
- 2648 Transition Edge Sensors (TES) @ 300 mK
- Cryogenic ASIC-SQUIDs for Time Domain Multiplexing (TDM)

Preliminary results from the instrument in its current state observing the moon @ 150 GHz

Observation at preliminary installation of the instrument in Alto Chomillos in October 2022

Upgrade proposal: Magnetic Microbolometers (MMBs)
New technologies developed in ITeDA & KIT to be evaluated by the collaboration

- Novel superconducting development using paramagnetic thermometers
- Photon limited sensor noise
- Fully superconducting system, reducing power dissipation compared to TES
- Measurement system using RF SQUIDs that avoids the use of closed-loop systems at cryogenic temperatures

Upgrade proposal: Paramagnetic cryogenic sensors and their Read Out electronics
New technologies developed in ITeDA & KIT to be evaluated by the collaboration

- 2048 Metallic Bolometer Array
 - Double multichroic polarization
 - RF SQUIDs (μ MUX) multiplexing
 - 4 MHz resonator spacing
 - 200 KHz resonator bandwidth
 - Resonant frequencies of 4-8 GHz
 - Flux ramp modulation
- Software Defined Radio (SDR) room temperature readout system

Conclusions:

- Preliminary results show QUBIC's interferometric capabilities by measuring the moon's spectrum
- Hardware upgrade to improve the resolution developed jointly between UNSAM and the tested KIT
- Instrument installed and working in its final site in Alto Chomillos, Salta

See Also: MMB sensors (A01-1062, A03-1299, A08-1045), MMB RF readout (B01-1098, B02-146, B02-1039, B02-1066)

Muchas Gracias



Dr. Alberto Lamagna
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Ing. Cristian Arrieta
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Dr. Alejandro Almela
Dr. Matias Hampel
Ing. Luciano Ferreyro
Ing. Manuel Garcia Redondo
Ing. Juan Salum
Dr. Manuel Platino

Ing. Juan Manuel Geria
Ing. Nahuel Müller
Ing. Andres Didonato
Ing. Claudio Ferrari
Ing. Enrico Petriela
Mg. Ing. Alejandro Fasciswski
Dr. Matias Wegner
Ms. Diego Perez Gagni
Tec. Dante Mercado
Tec. Diego Silva
Lic. Belén Manente
Lic. Micaela Álvarez
Prof. Dr. José F. Bonaparte

