Cryogenic detectors

Retreat Sezione di Roma – 18/06/2019

Angelo Cruciani

(very!) Brief introduction

- Cryogenic detectors needs to operate below 10 K. Typical temperature is below 300 mk.

- They can be operated as calorimeter or bolometer (Power detector).

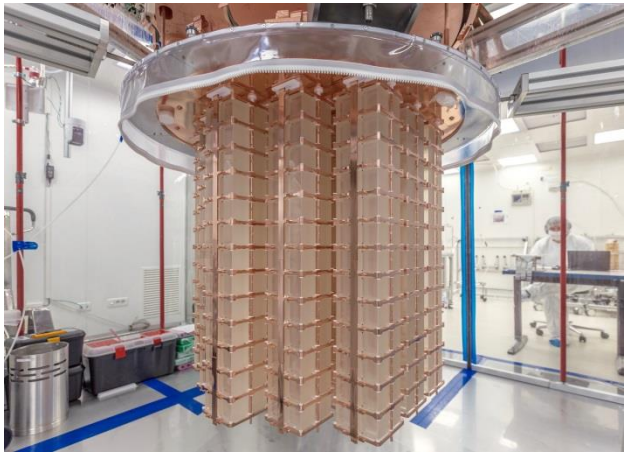
- 3 main technologies:
  1) ***NTD Ge thermistor:***

     thermal detector, not multipexable, medium sensitivity, slow device
  2) ***Transition Edge Sensor (TES):***

     (mainly) thermal detector, multiplexable, high sensitivity, fast device (expansive and complex)
  3) ***Kinetic Inductance Detector (KID):***

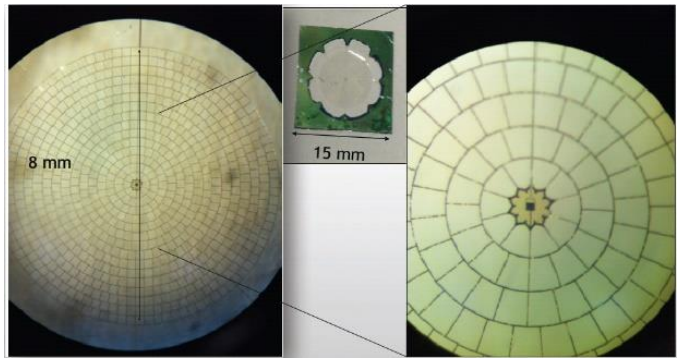
     direct detectors, RF High-Q resonators, easy to multiplex, medium sensitivity, fast device

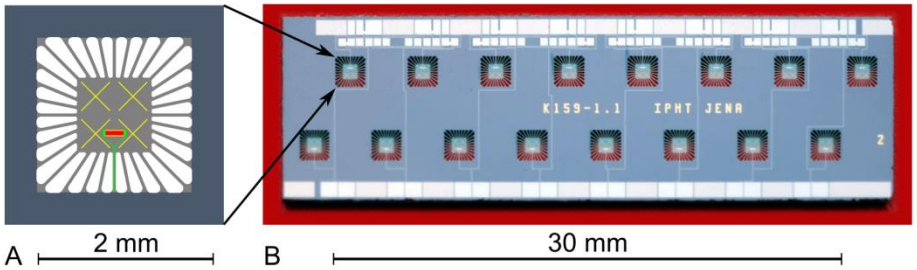
Which applications?



- 0nu double beta decay
- Neutrino mass
- Dark Matter
- Coherent neutrino scattering

- CMB observation
- Sub-mm e mm astronomy
- X-ray astronomy
- UV-VIS-IR astronomy
  (planetology, galaxy survey)





- Quantum comunication and
  compunting
- Homeland security
- Cultural Heritage
- Life Science

Overview of on-going activity

Laboratorio di rivelatori criogenici:

F. Bellini, L. Cardani, N. Casali, I. Colantoni,

A. Cruciani, M. Vignati

CALDER (CSN 2)
BULLKID (CSN 5)
CUPID0 (CSN 2)
DEMETRA–AQUILA(CSN 5)

Experimental Cosmology Group (G31)

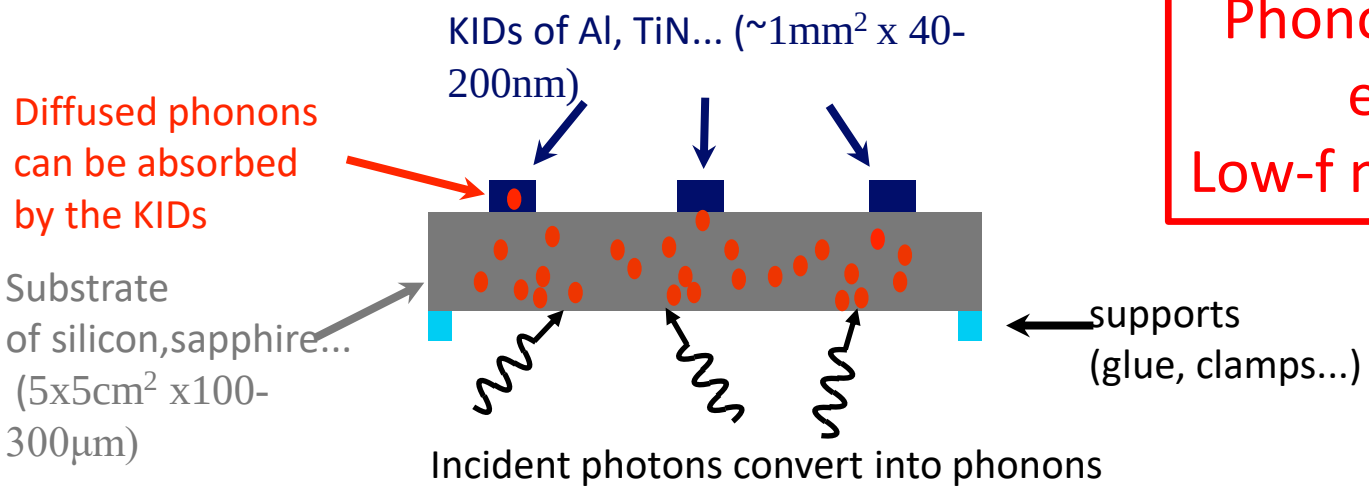
E.S. Battistelli, A. Coppolecchia, G. d'Alessandro,
P. De Bernardis, L. Lamagna, S. Masi, A. Paiella, F.
Piacentini

OLIMPO
LSPE (CSN 2)
QUBIC (CSN 2)

CALDER project

CALDER is an ERC-SG project, ending in 2019

Goal: The development of KIDs light detectors on 5x5 cm^2 surface and with high resolution (σ = 20 eV RMS) for CUPID



MAIN CHALLANGES:
Phonon absorption efficiency
Low-f noise reduction

Battistelli et al., EPJ C 75 353 (2015)

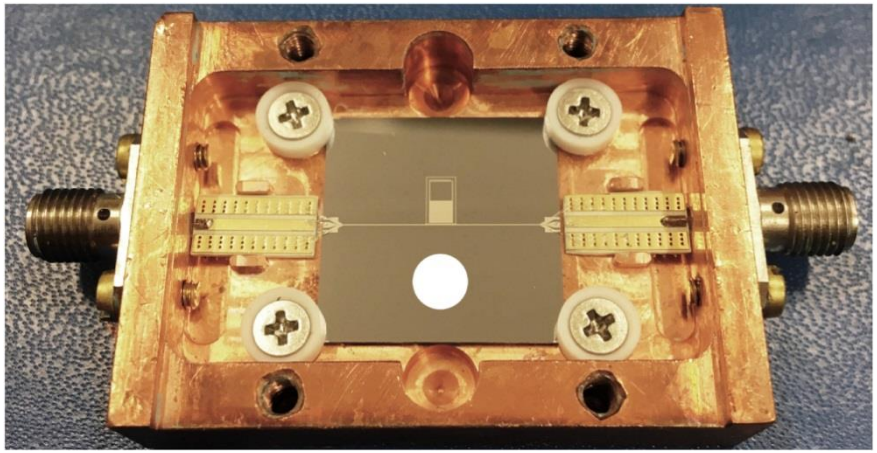
CALDER results

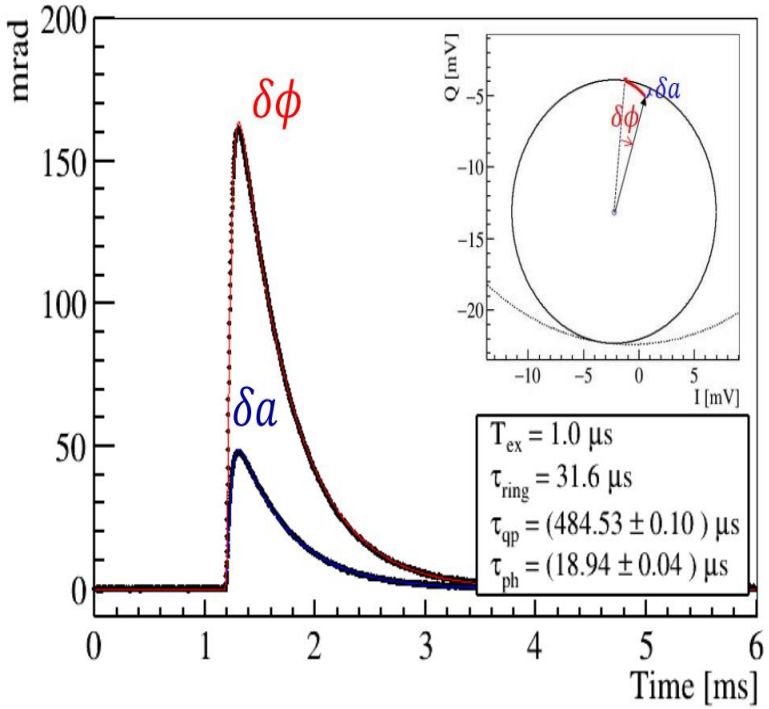
Best baseline resolution:

50 eV for Aluminium

25 eV for Al/Ti/Al trilayer

Typical phonon efficiency: 10%





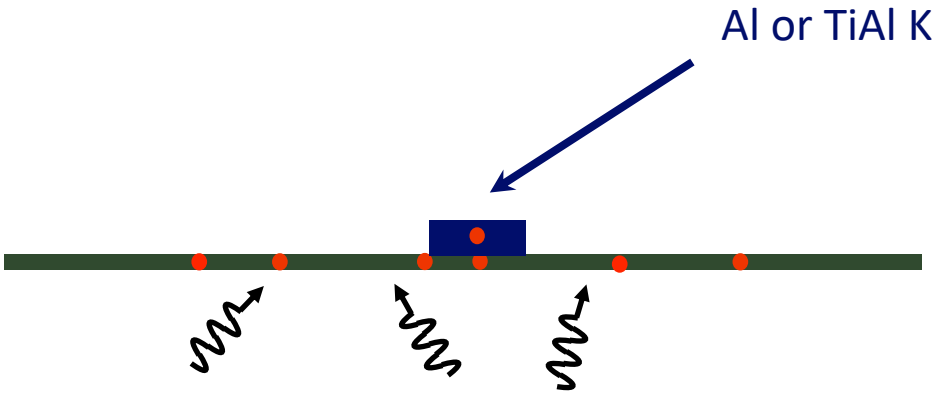
Cardani et al., APL 107 093508 (2015)
Cardani et al., APL 110 033504 (2017)
Cardani et al., SUST 31 075002 (2018)
Martinez et al., PHYS REV APPL **11,** 064025 (2019)

BULLKID

BULLKID (2-yrs CSN5 R&D) aims at a detector of athermal phonons created by nuclear recoils induced by Dark Matter or neutrino scattering.

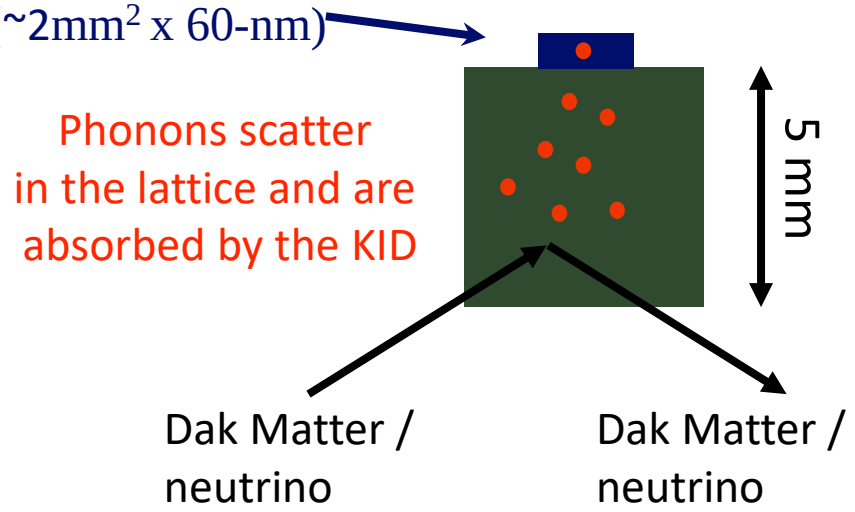
Mass: increase the detector mass with KIDs on 5 mm instead of 300 µm thick wafers.

Threshold: reach 20 eVnr threshold acting on the phonon absorption and on the KID sensitivity (25 eV σ demonstrated by CALDER).



CALDER

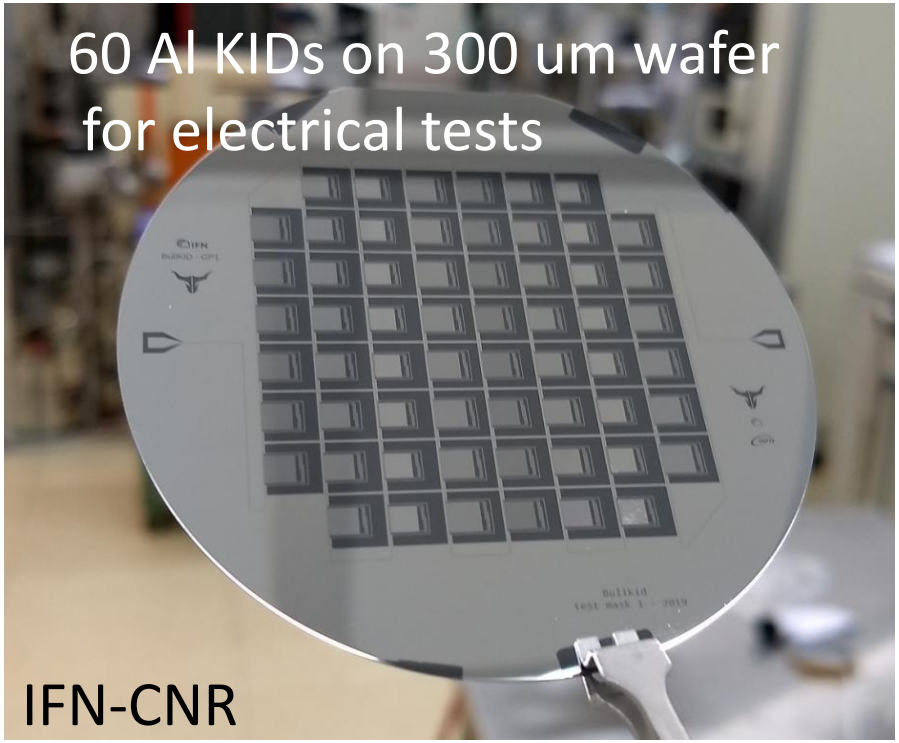
Silicon (2x2 cm^2 x300 µm)

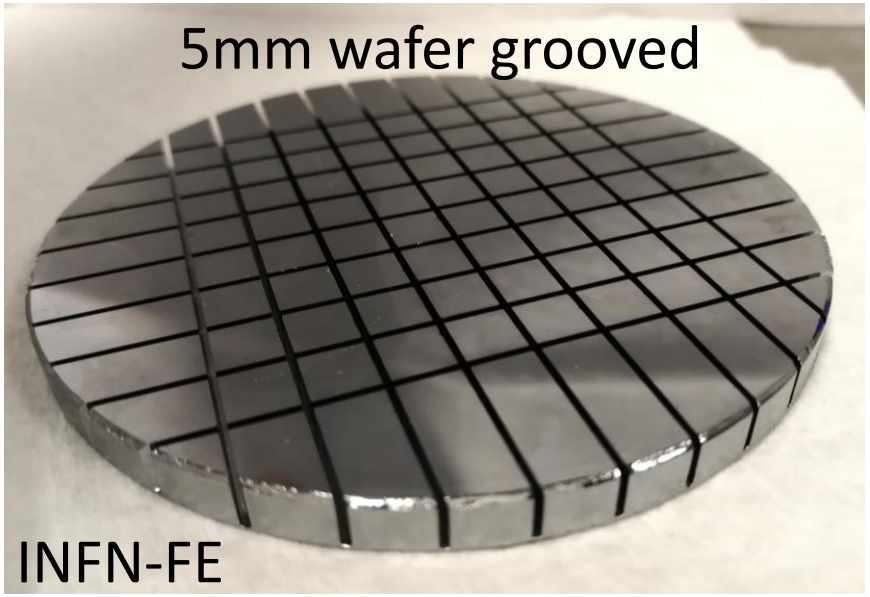


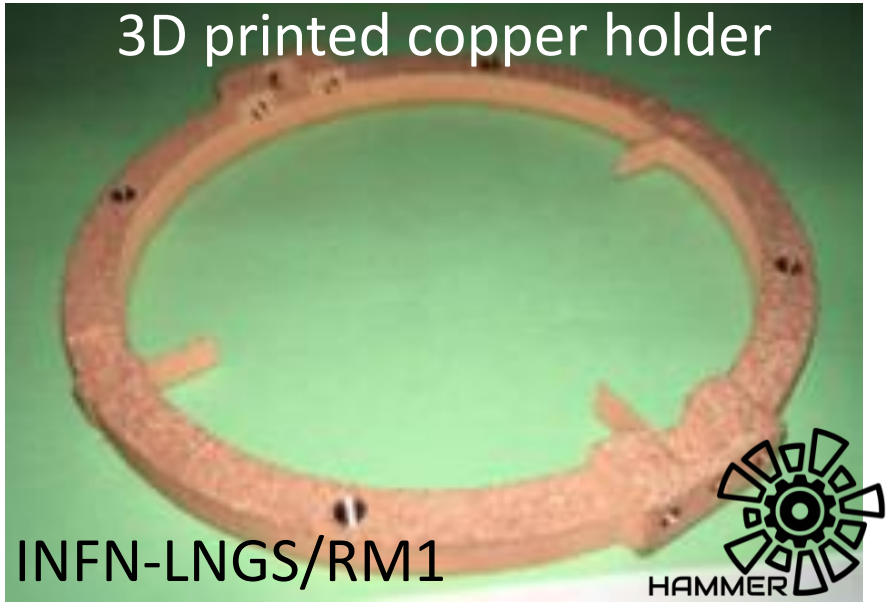
BULLKID

Silicon (5x5x5 mm^3)

BULLKID status



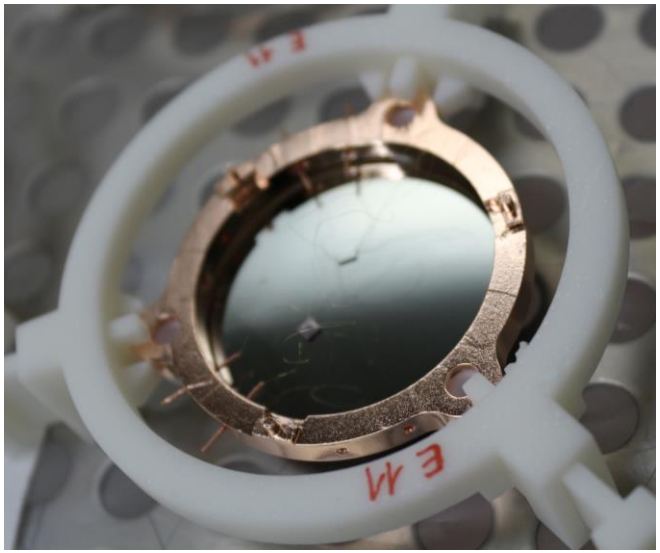




CUPID-0 assembly

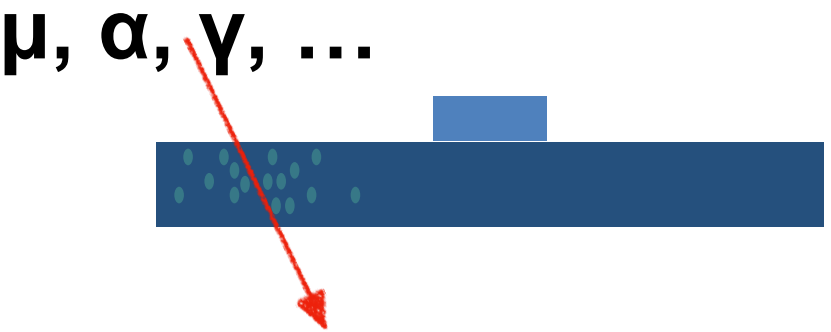
26 ZnSe cryogenic calorimeters with light detectors installed in ultra-clean enviroment

- Design and development of a motorized garage for the tower assembly
- Design and realization of all the components for the light detectors mount
- Project and realization of the detector storage and assembly

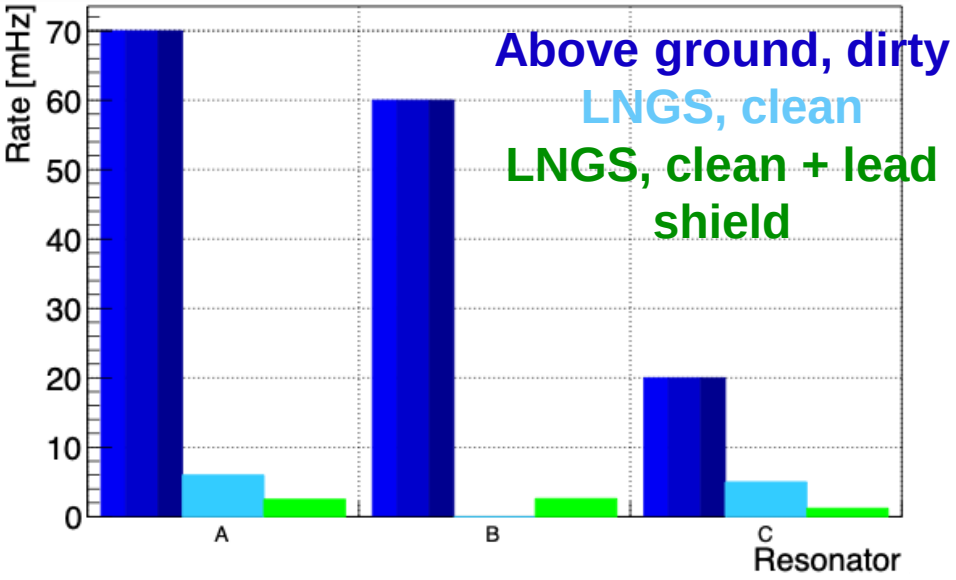


DEMETRA/AQUILA

- **Coherence time in a QUBIT limited by several mechanisms**
- **One of the most important: quasiparticles**
- **DEMETRA/AQUILA: contribution of radioactivity and CRs to quasiparticle creation**



First results prove that quasiparticles bursts can be induced by radioactive interactions in the substrate: qubits can see radioactivity from the substrate

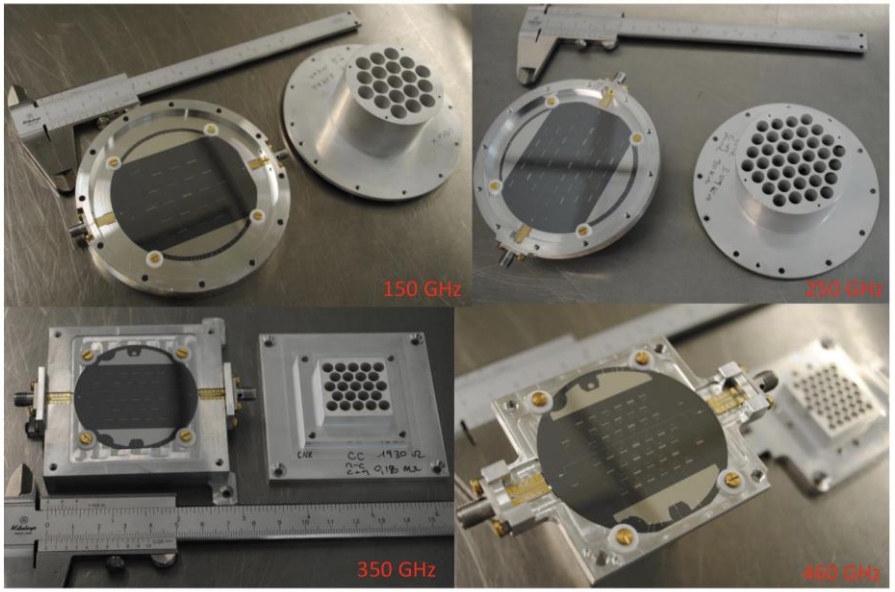


DEMETRA/AQUILA: Perspectives

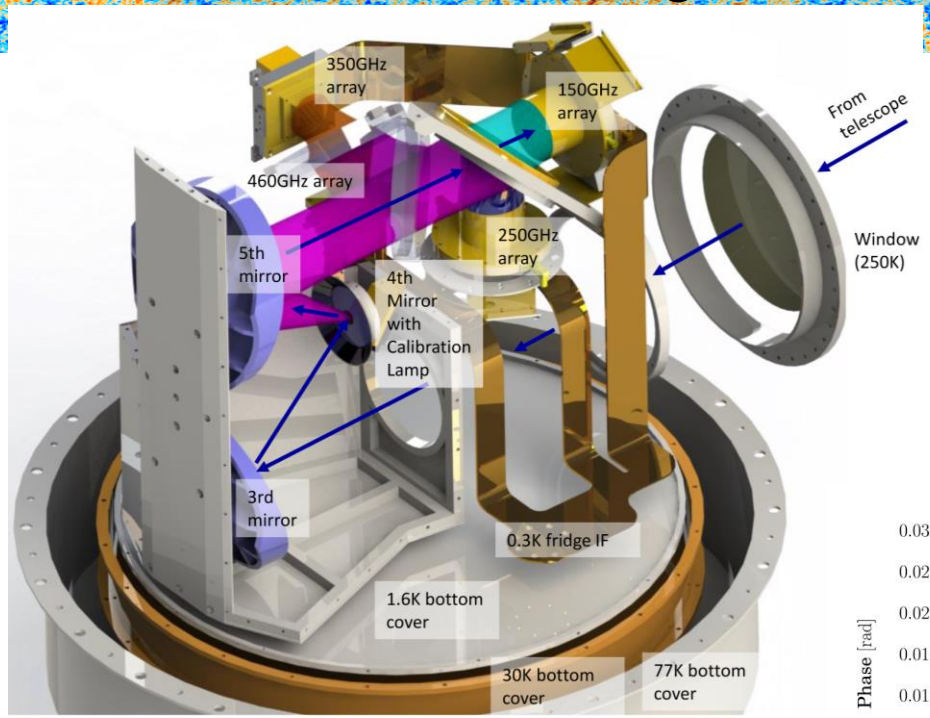
- Initially supported with 20 keuro (L. Cardani's INFN starting grant)
- Growing interest, a larger project (AQUILA) submitted to QuantERA (5 institutions, 20 researcher, 1.3 M€)
- Passed first round of evaluation waiting for the final decision (end of summer)
- The aim is to prove that our community can give an essential contribution

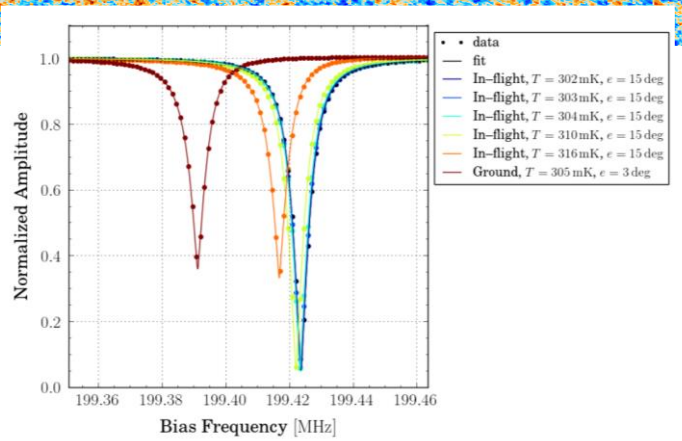
Kinetic Inductance Detectors for the Cosmic Microwave Background

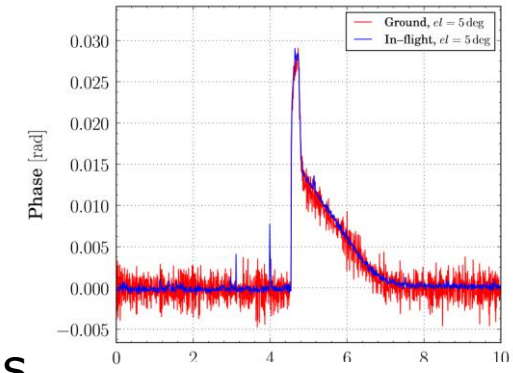
- Development of arrays of feedhorn-coupled Al Lumped-Elements KIDs for the CMB, operated at 0.3K.
- Development started 10 years ago as a INFN-CSN5 activity (coordinator P. de Bernardis); subsequent tailoring for space missions funded by ASI.
- Design, integration and testing in Roma1, wafer processing in CNR-IFN
- Latest achievement: July 2018, first use of KIDs in near space with the OLIMPO stratospheric balloon telescope (S. Masi).
- See: Paiella et al. JCAP01(2019)039, Masi et al. 2019 arXiv:1902.08993 .



OLIMPO detectors results: calibration and performance of KIDs for the CMB on the ground and in flight







Channel [GHz]	N_g/N_f	average NET_{RJ} $[\mu K\sqrt{s}]$	
		ground [25]	in–flight
150	2.5	201	81
250	8	243	30
350	3.5	243	69
460	5	336	67

- Excellent in-flight performances
- First proof of effect of CR hits on this detectors in view of forthcoming satellite missions

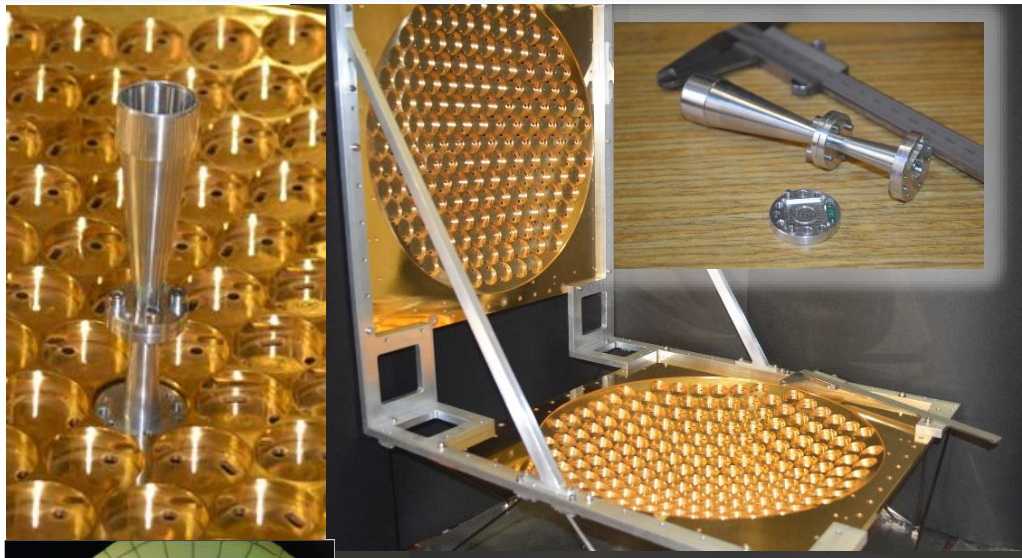
Array	Working pixels	$f(>3\sigma_c)$	$f(>3\sigma_c) - f(<-3\sigma_c)$
150 GHz	20	1.5%	1.2%
250 GHz	34	1.0%	0.4%
350 GHz	23	0.4%	0.1%
460 GHz	43	0.4%	0.2%

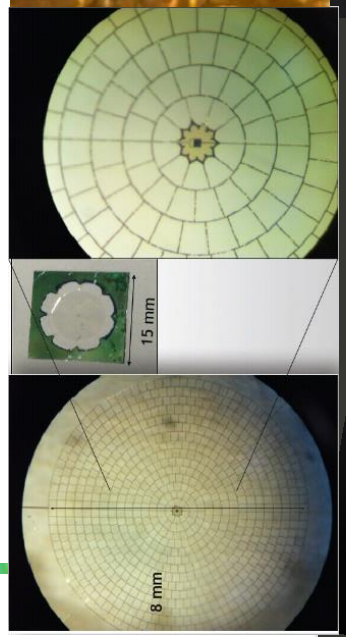
Table 3. Fraction of samples with values $> 3\sigma_c$ in a 820 s long stable–pointing period (total 100000 samples per pixel), for the four arrays of the experiment. To compute the fractions, we coadded all the events of all the pixels of the same array. The fraction of data contaminated by CR hits is small for all the pixels of all the arrays.

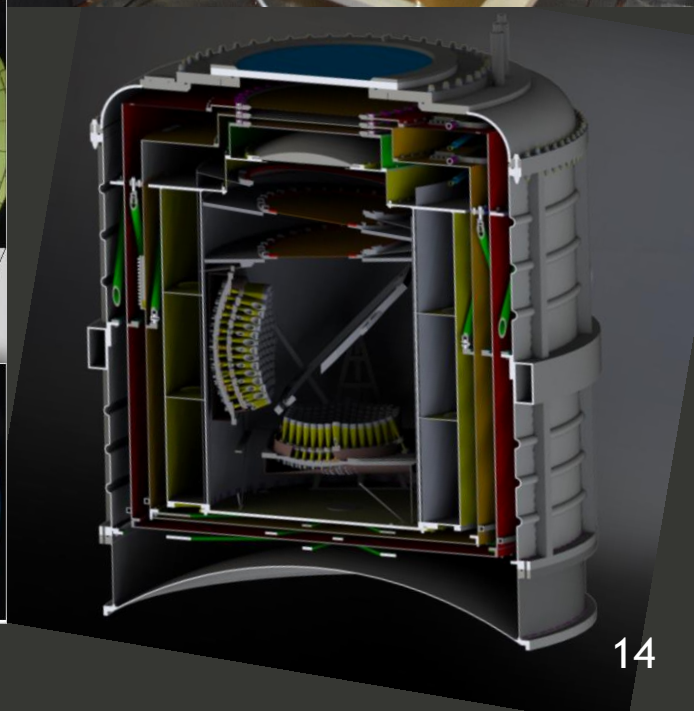
See Paiella et al. 2019
Masi et al. 2019

Polarimeter development, Detectors Integration and Calibration for LSPE-SWIPE

- The SWIPE instrument (*PI de Bernardis*) of the Large-Scale Polarization Explorer is a CMB polarimetry mission on a stratospheric balloon, to be flown in the Arctic night in 2020.
- Funded by ASI, Sapienza, and INFN
- The cryostat, telescope, polarization modulator, multimode feedhorns and the focal plane are developed in Roma1, while the TES detectors and its electronics are developed in INFN Genova and INFN Pisa
- **Dedicated focal-plane integration facility in Roma1. Dedicated polarimetry test facility in Roma1 (G31).**

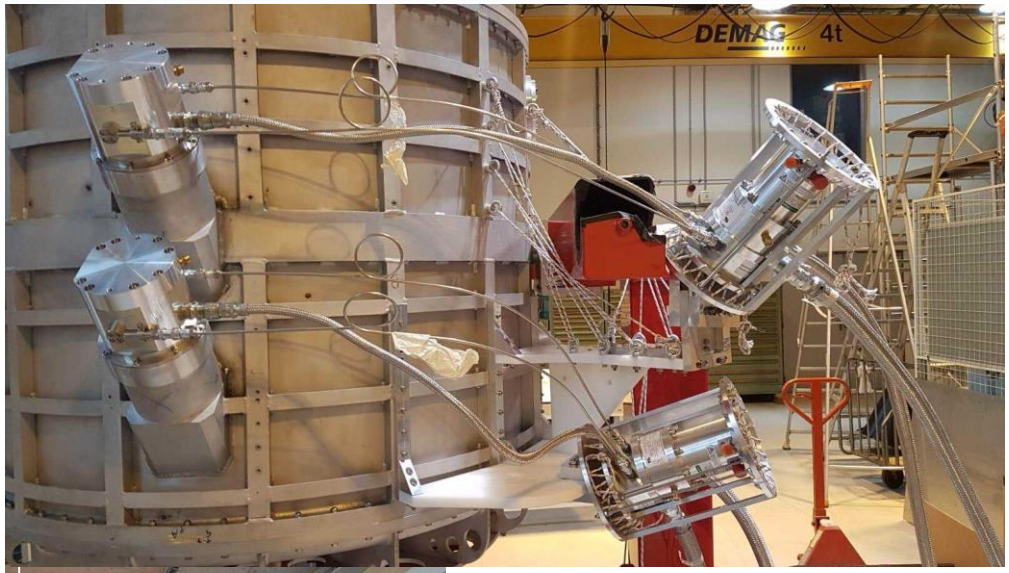


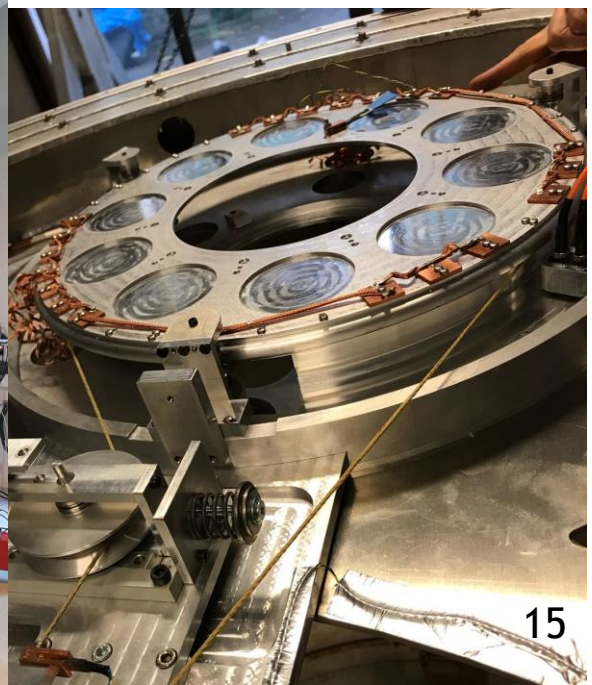




Polarimeter development, Cryogenic System and Detectors calibration for the QUBIC experiment

- The QUBIC experiment (PI J.C. Hamilton) measures CMB polarization from the high altitude Argentinian Andes, using an innovative bolometric interferometer.
- Important INFN contributions (Coordinator S. Masi, Roma1):
- **Cryogenic system (Roma1)**, feedhorns array (Mi), beam combiner and optical switches array (MiB), data analysis (Roma2).
- **Custom full-beam calibrator for accurate polarimetry developed in Roma1.**
- Currently in demonstration phase. Shipment to Argentina by end of 2019.





Skills @ Roma1

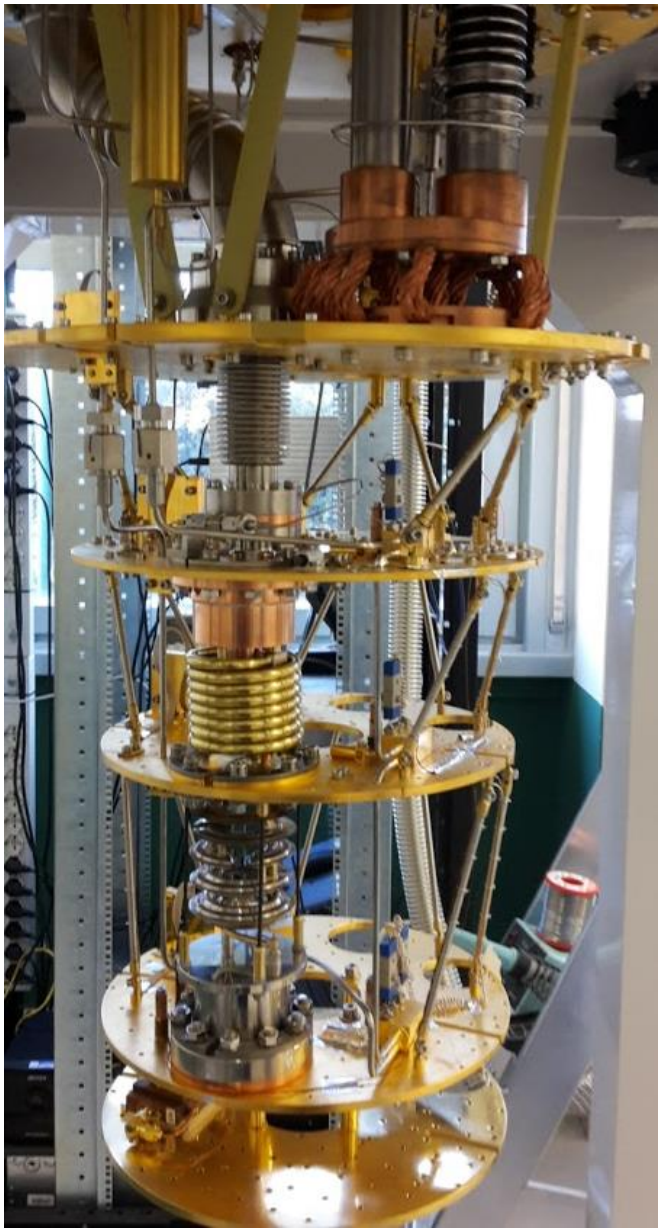
- Cryogenics down to mK
- Detector development (KID)
- Detector test and integration in experiments (KID, TES, NTD)
- RF (cryogenic) electronics assembly
- SQUID electronics development
- Microfabrication

What is missing?

- FPGA/GPU electronics development

in continuous collaboration with:
Officina meccanica
LABE
Progettazione Meccanica

Facilities @ Roma1



Laboratorio di Rivelatori Criogenici:

- A 10 mK Oxford dilution refrigerator installed in 2016 (CALDER + ROMA1 + SAPIENZA)
- Semi-automatic wedge-ball bonder forthcoming (CALDER + ROMA1)

Experimental Cosmology Group

- 2 sub-K refrigerator for device testing
- A small CR with laser lithography (micron scale) and a wedge bonder

What is missing?

- Microfabrication equipment (sputtering machine, mask-aligner, etc) to allow in-house fabrication of the devices