TES for CMB

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Overview

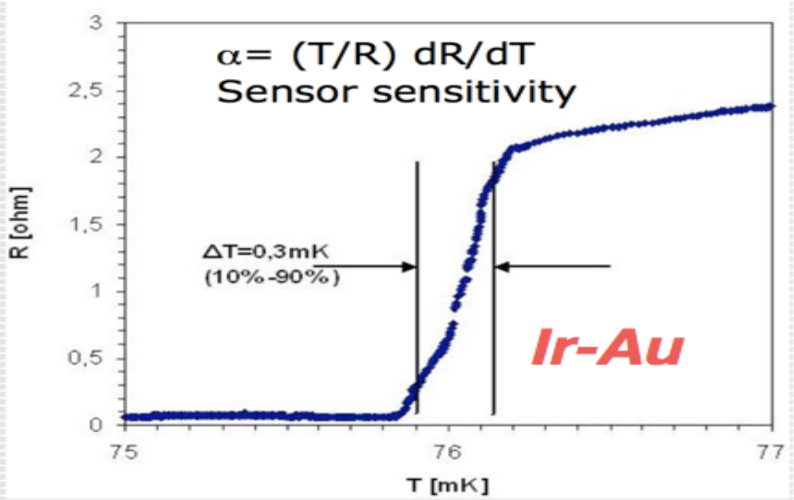
1. CMB TES Bolometers:

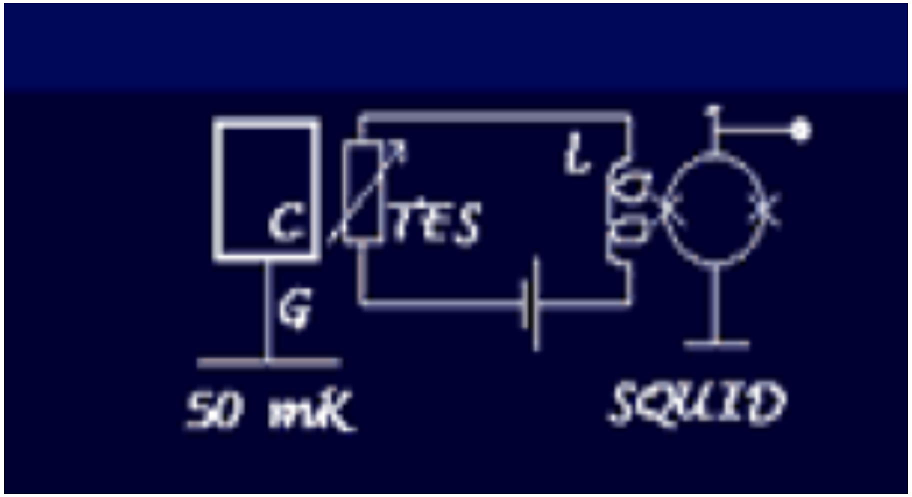
   Physics, Performance, Application,

2. Status of the Art
3. Groups in Europe

TES

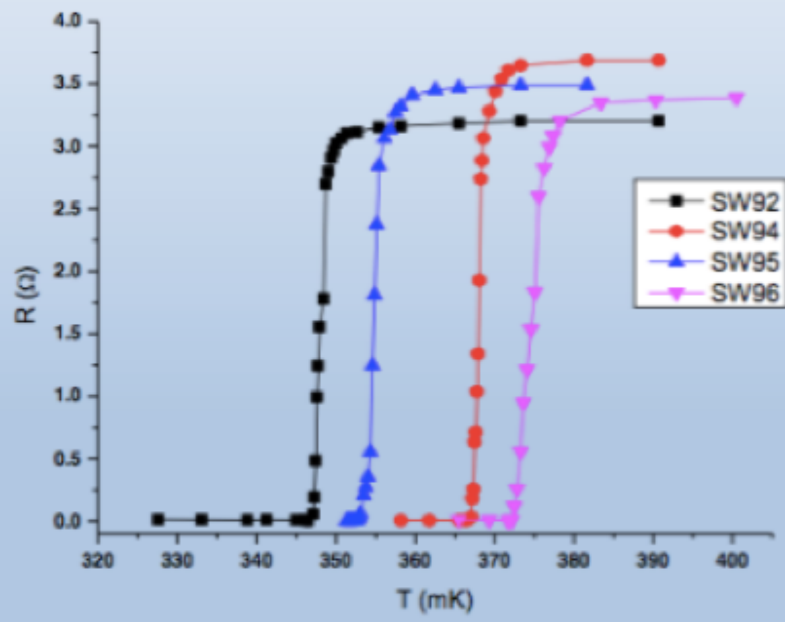
- Superconducting film operated in the s/c to normal transition
- SQUID as best matching current amplifier
- Low T → Low Noise Equivalent Power to input and narrow transitions
- Multiplexing schemes TDM and FDM are suitable





TES performance test

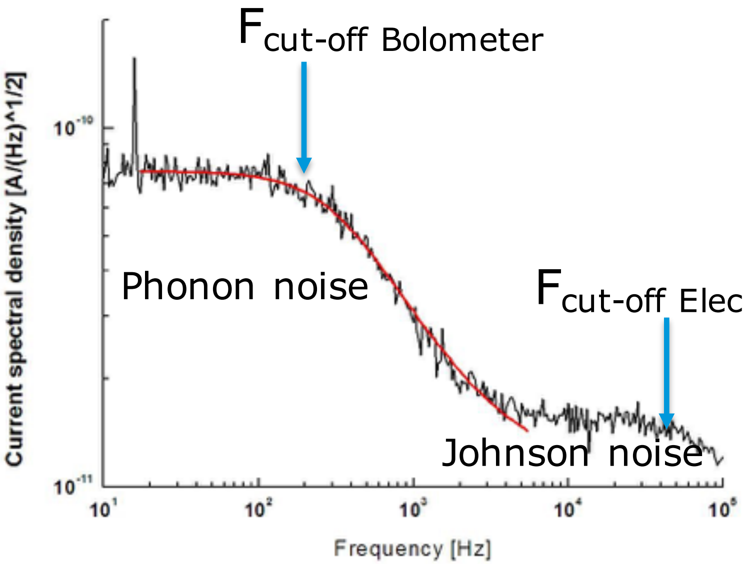
- Bilayer TES Ti-Au studied for covering 0.3 -0.4 K
- Larger temperature range requirements (0.5K): Investigations on Ti and Mo films proximized with gold

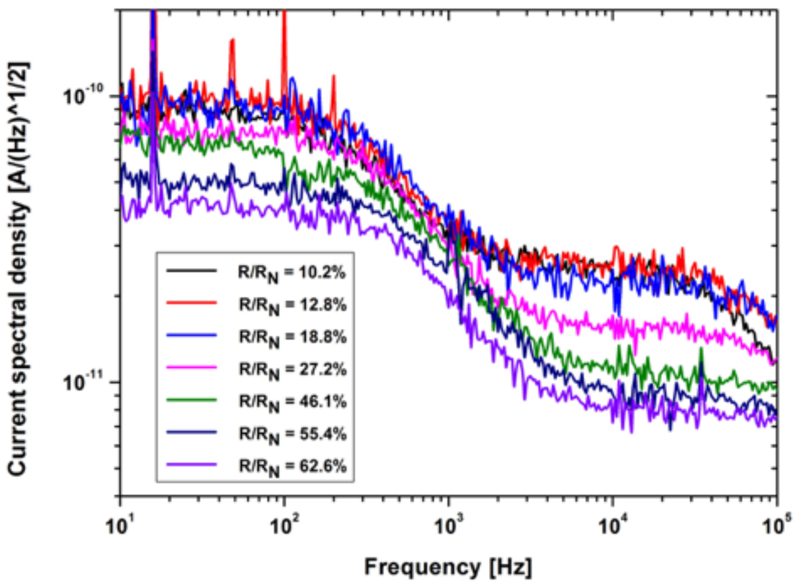


	Ti (nm)	Au (nm)	Ti (nm)
SW92	5.0	4.4	37.2
SW94	5.0	4.4	38.0
SW95	5.0	3.8	37.2
SW96	5.0	3.8	38.0

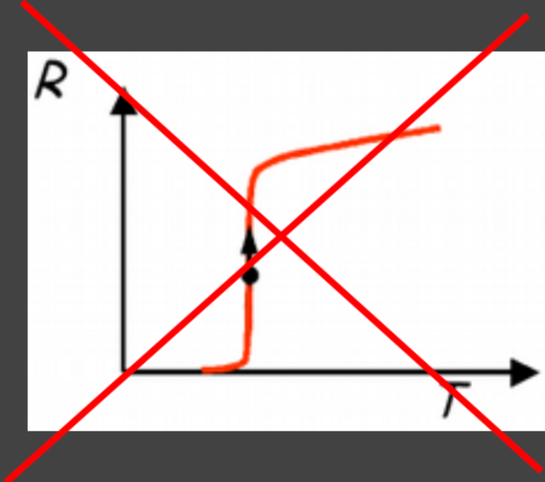
TES Performance tests

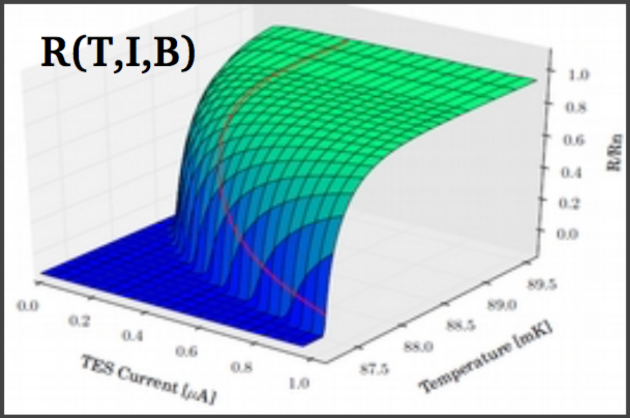
1. Bolometer in isothermal box at low T (no external EM radiation)
2. TES at several operating points (R/Rn)
3. Current Noise as composition of [phonon noise x bolometer gain] and Johnson noise; SQUID noise at $1x10^{-12}$ A/Hz.





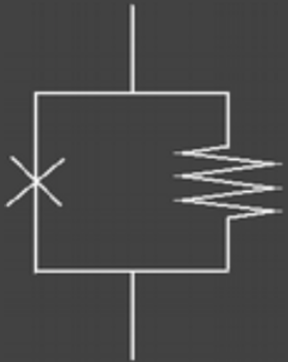
Progress in understanding the TES physics

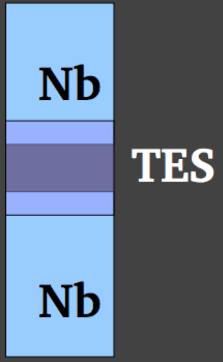




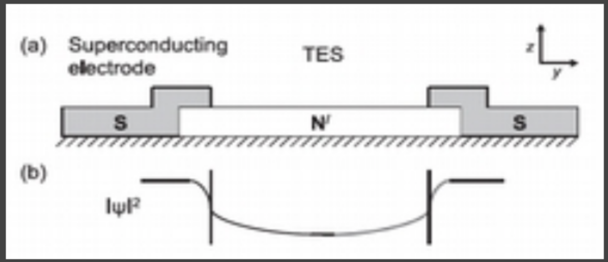
$J_J = J_o \sin \phi$

$L_J = L_{J\,o} \cos^{-1} \phi$

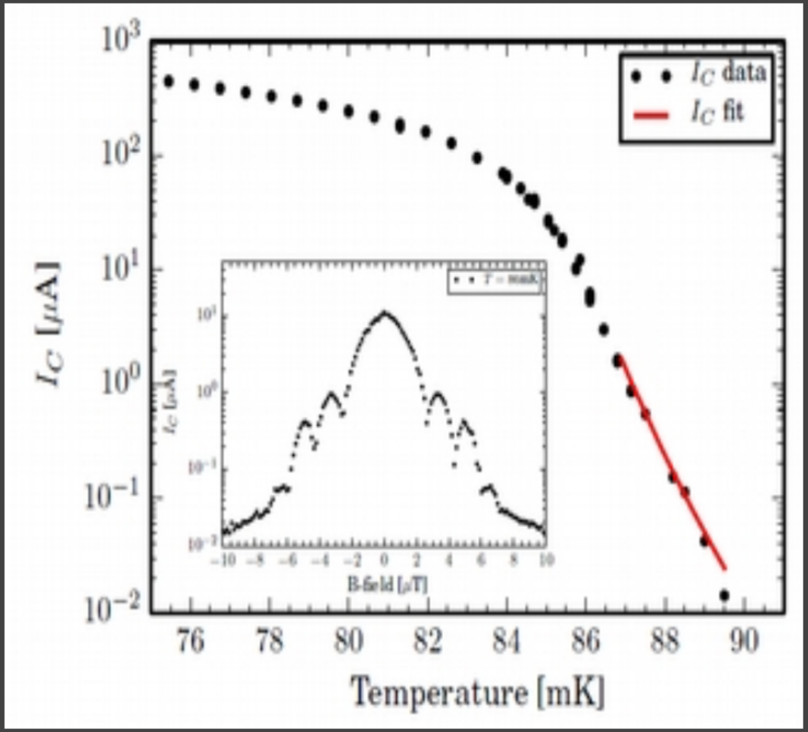




J. Sadleir *et al.* PRL 104, 047003 (2010)
A. Kozorezov *et al.* APL, 99,063503 (2011)
S. Smith *et al.* JAP,114, 074153 (2013)
L. Gottardi *et al.* APL, 105, (2014)
J.Ullom and D. Bennett ,Superc.Sci.Tech. 28 (2015)

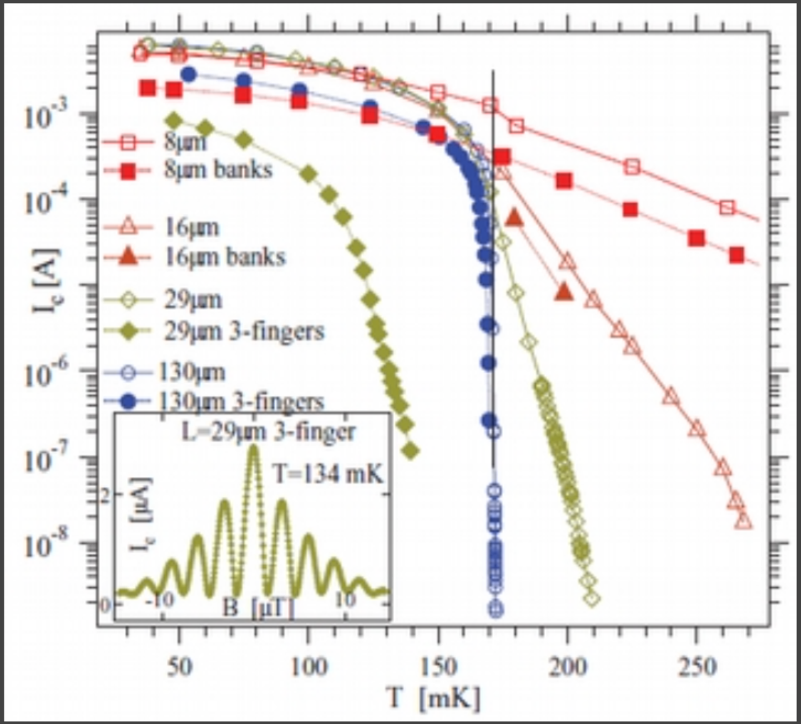


SRON bolometers (ac-bias)



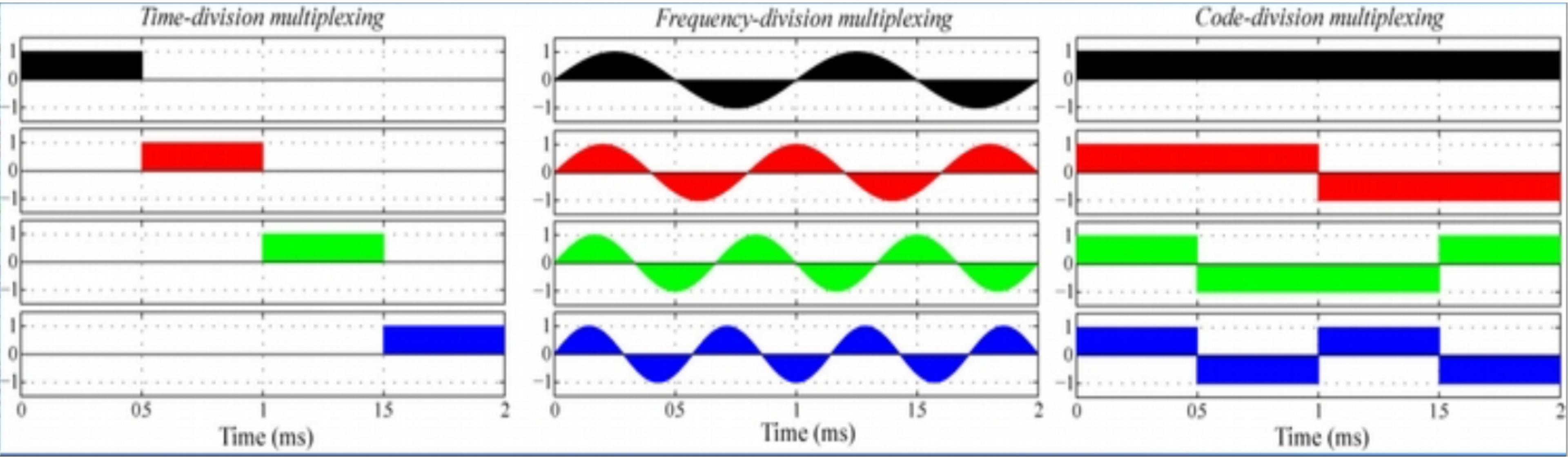
L. Gottardi *et al.* APL, 105, (2014)

GSFC micro-calorimeters (dc-bias)



J.Sadleir *et al.* PRL 104, 047003 (2010)
S.Smith *et al.* JAP,114, 074153 (2013)

- TES behaves as a **superconducting weak-link** due to proximity effect induced by the Nb leads
- Ic vs B → Fraunhofer-like pattern.
- Close to Tc, Ic decreases exponentially following weak-link theory



TDM

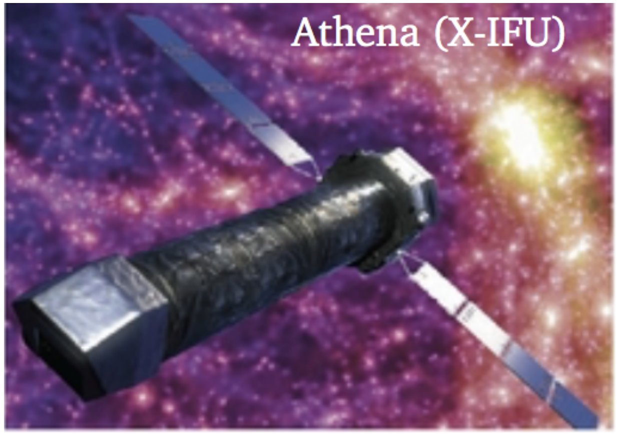
1. Multiplication of TES signal with *boxcar functions*
2. SQUIDs are switched ON and OFF in time
3. The SQUID amplifier is the modulating element

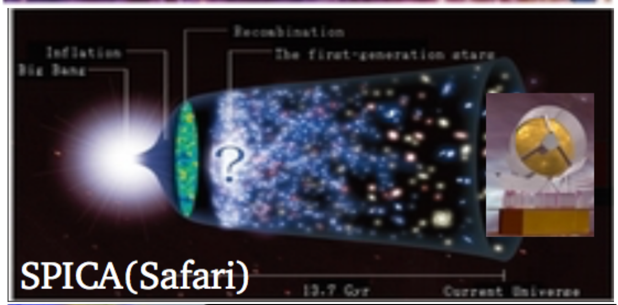
FDM

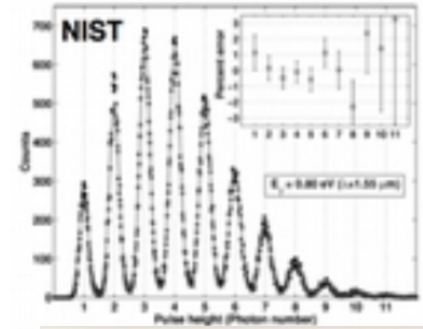
1. Multiplication of TES signal with *sine functions*
2. Requires noise blocking filters
3. Either the TES (**MHz-FDM**)or the SQUID (**GHz-FDM**) is the modulating element

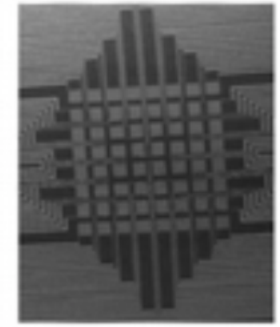
1. **CDM**
2. Use *Walsh-code* modulation functions
3. Pixels are on all the time SQUID or superc. switches as
4. modulating element

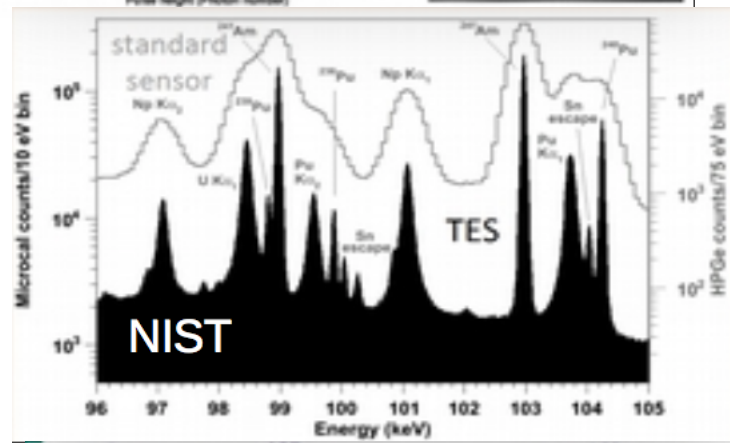
WIDE RANGE of APPLICATIONS

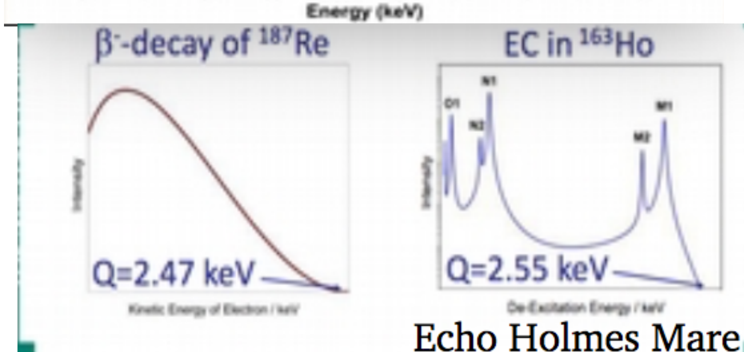


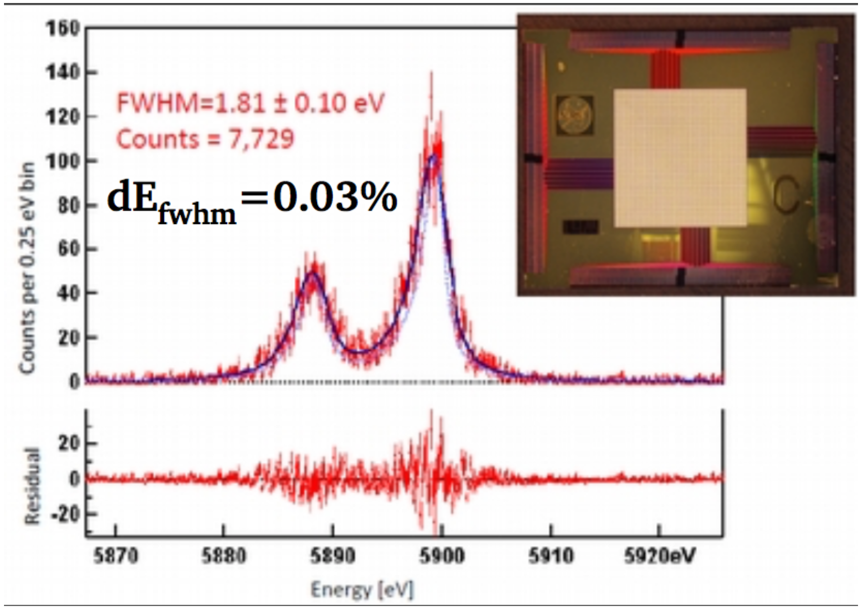


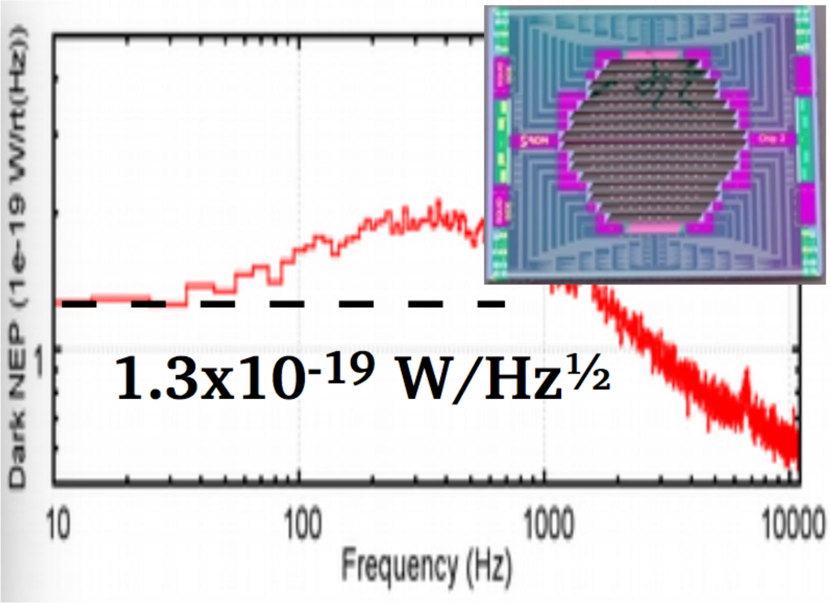










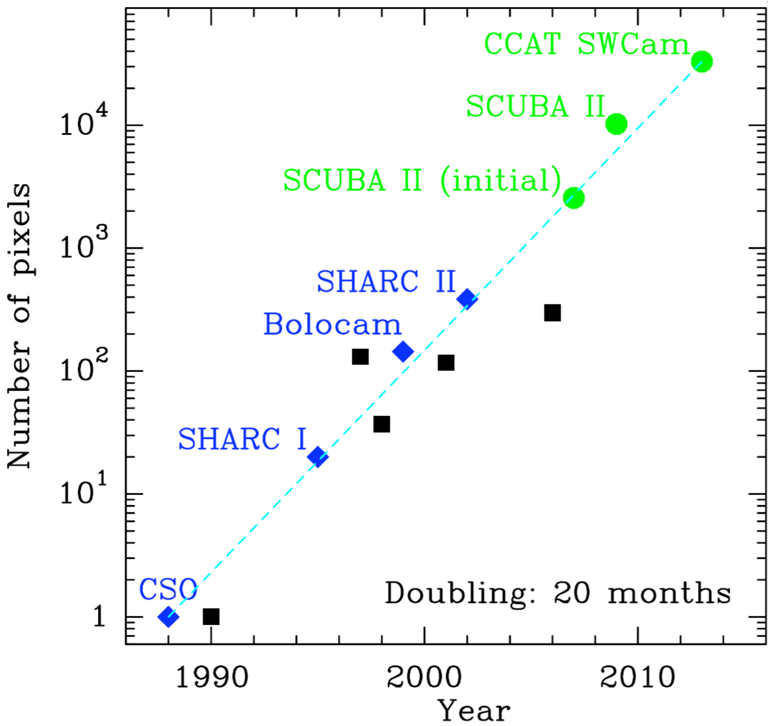


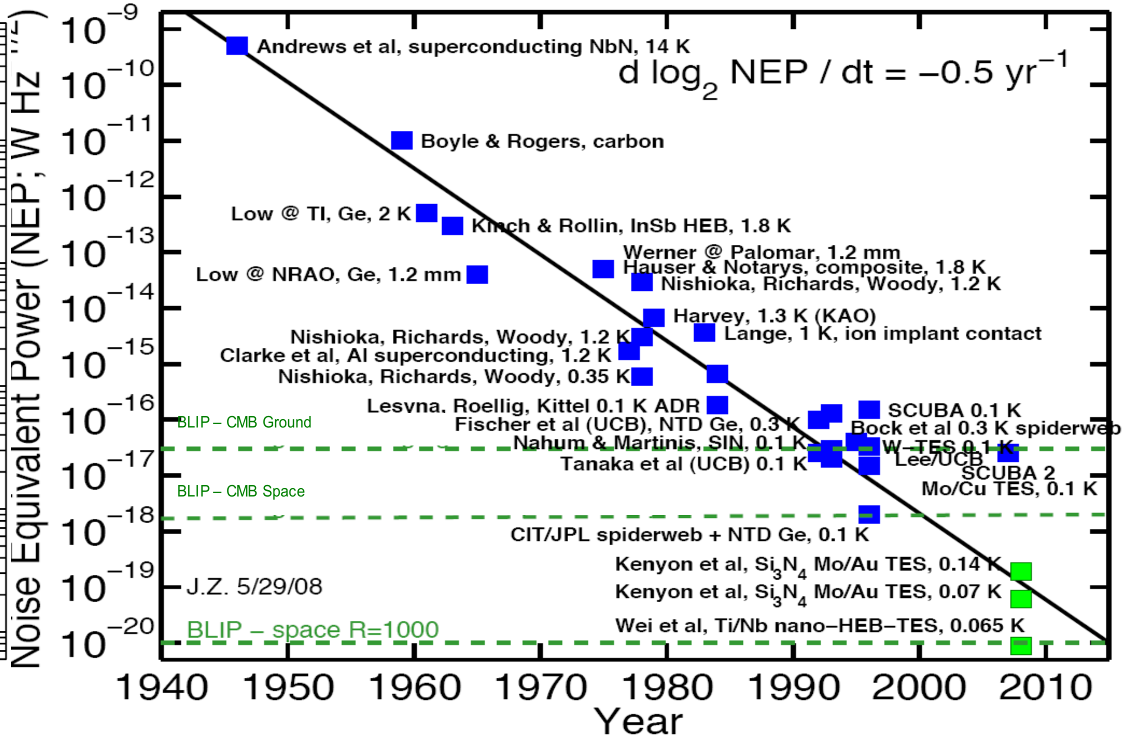
S.Bandler et al, GSFC NASA

T. Suzuki et al, SRON

Status of the art

- Array size: doubling time = 20 months
- NEP challenge: improves of about a factor 10 each 10 years





Not a complete list

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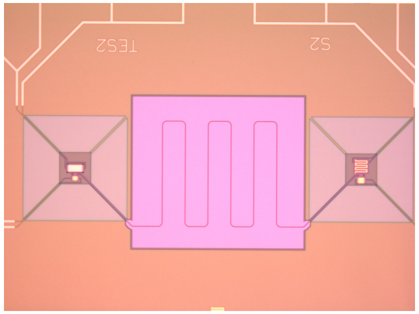
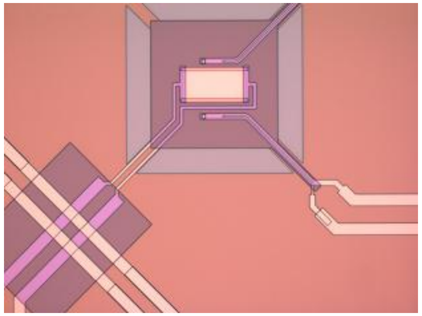
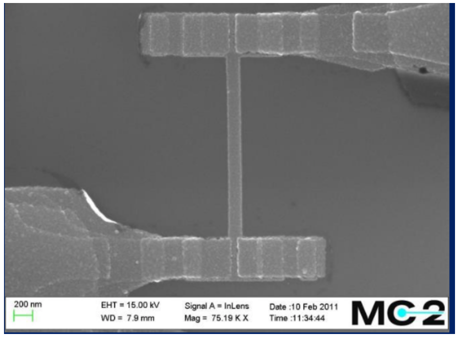




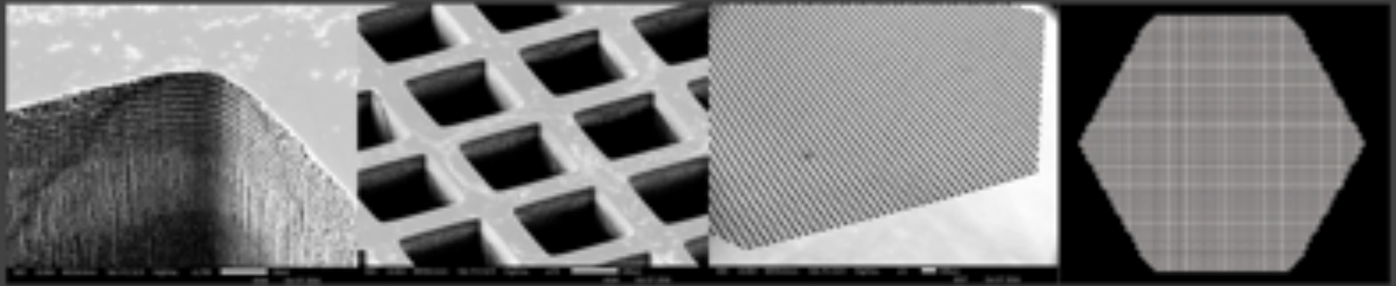
2. Germany: KIT,Jena,..



3. Sweden: Chalmers,..
4. The Netherland (Slides by SRON)
5. France (Slides by IRAP)
6. Italy: Genova, INRIM
7. Apologize for other TES Groups not cited here (Spain,…)

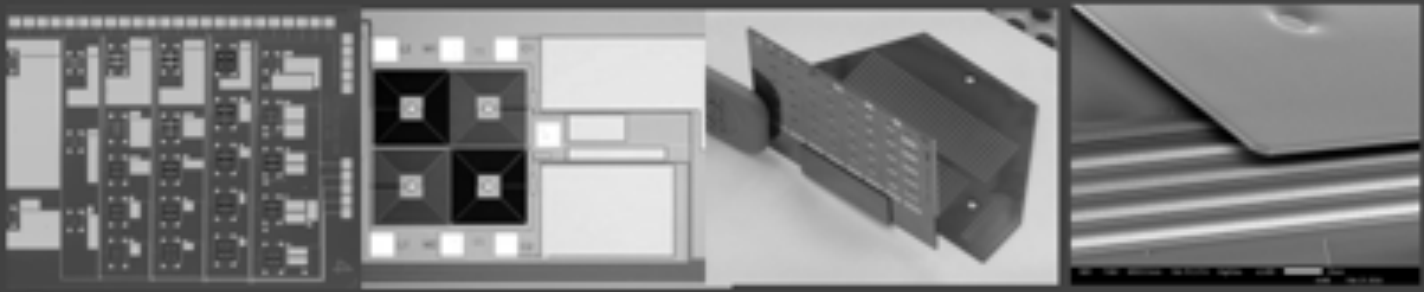
TES (FIR and x-ray) technology Development at SRON

DRIE method developed: Si Grid



Ultra low NEP TES Bolometers

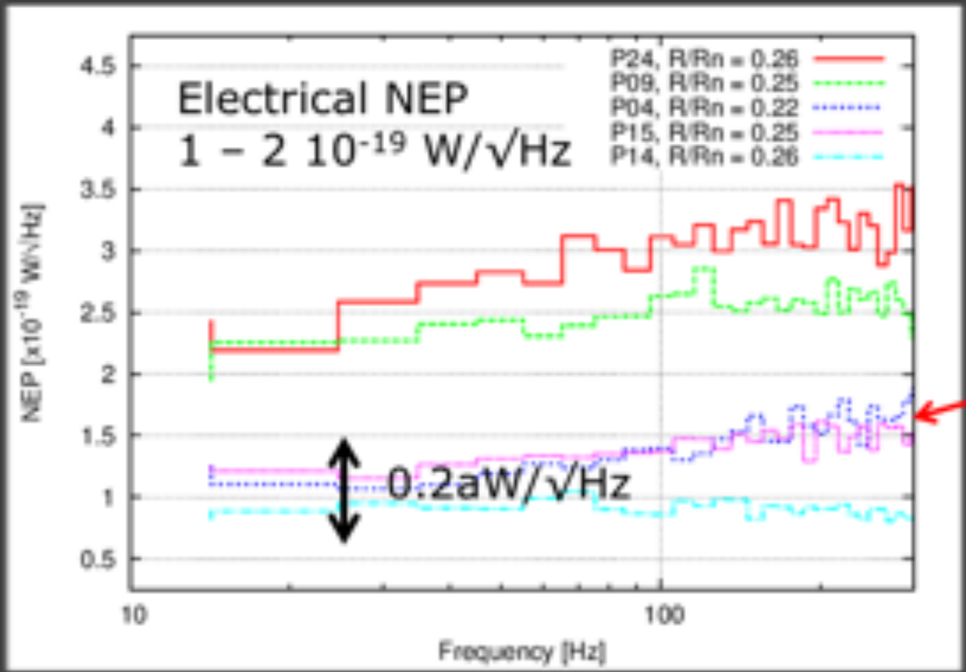
Lithographic LC filters, Flex connections , μ-stripline for FDM



SRON

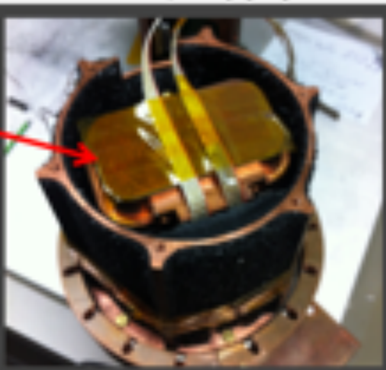
By Richard Hijmering and Jian-Rong Gao at SRON

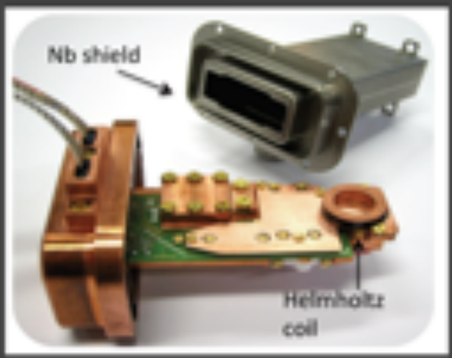
Ultra low-NEP bolometer arrays



TiAu TES on a thin SiN island

Truly dark set-up





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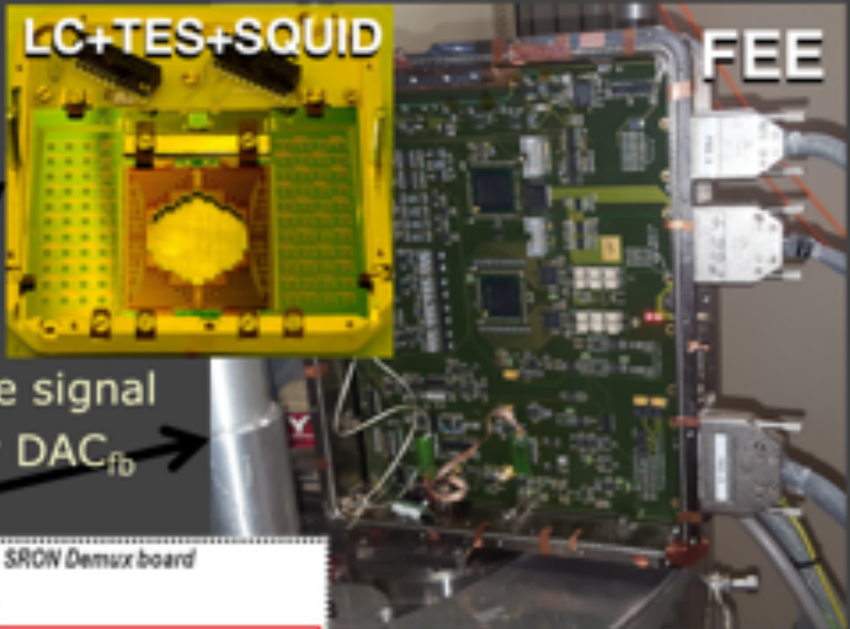
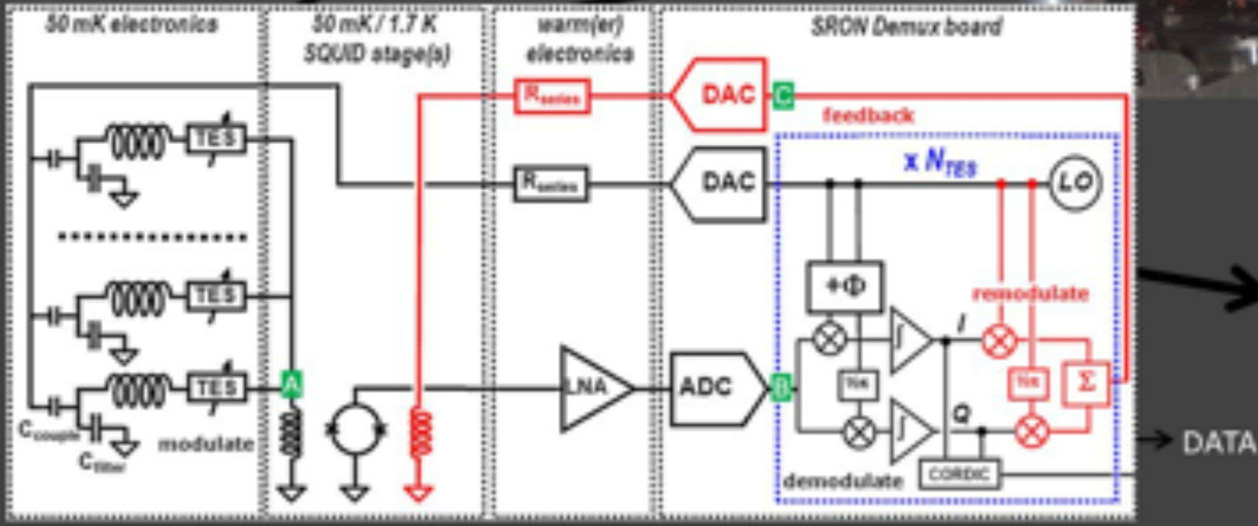
agenzia spaziale italiana

INFN

FDM readout electronics

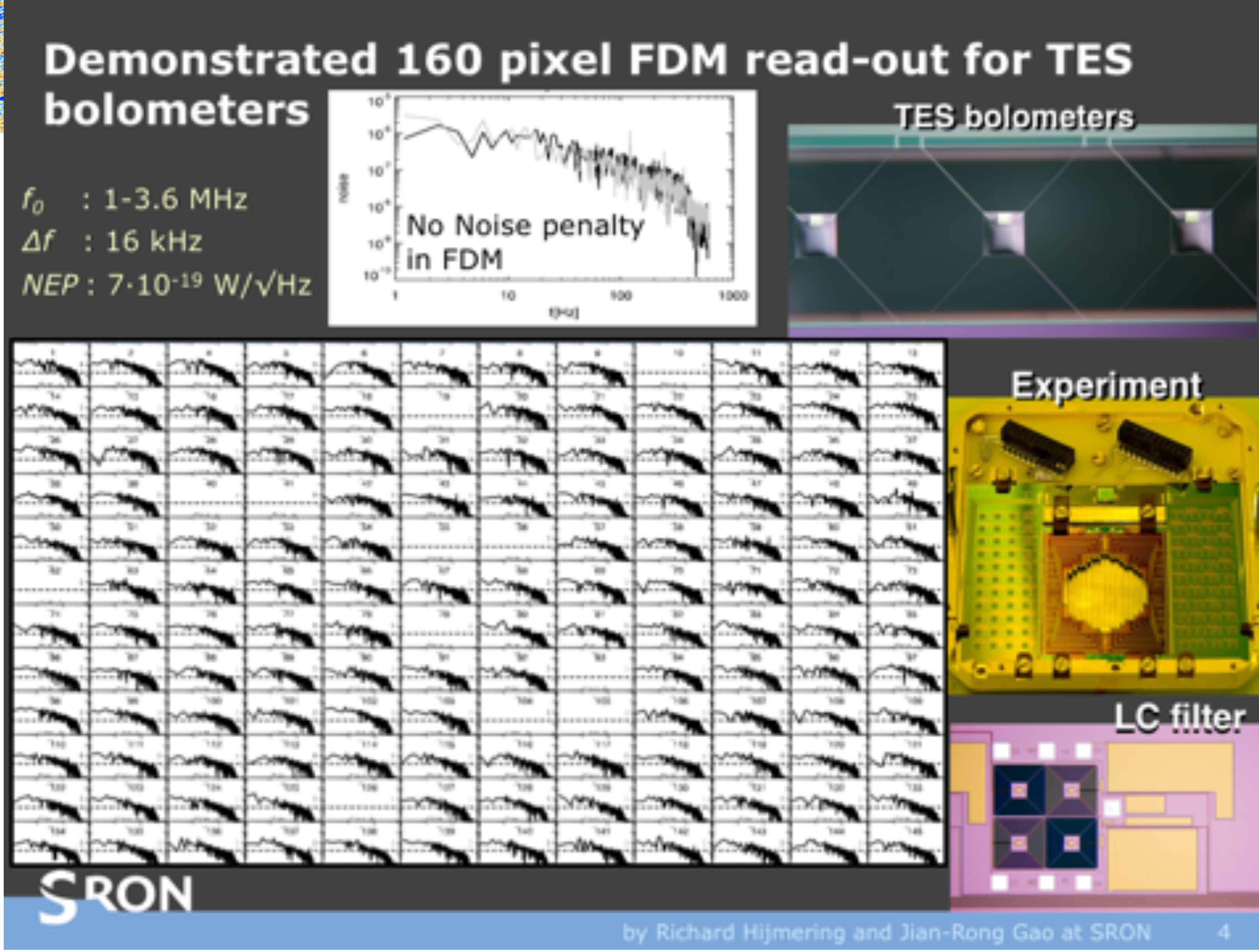
- DAC_{bias} supplied bias carriers
- Filtered one per TES by LC filter
- Summed at SQUID amplifier
- Amplified by LNA
- ADC demodulated I and Q give the signal
- Remodulated send to input coil by DAC_{fb}





SRON All developed in-house

By Richard Hijmering and Jian-Rong Gao at SRON



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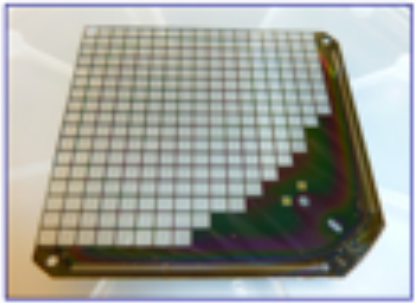
TES developments in France

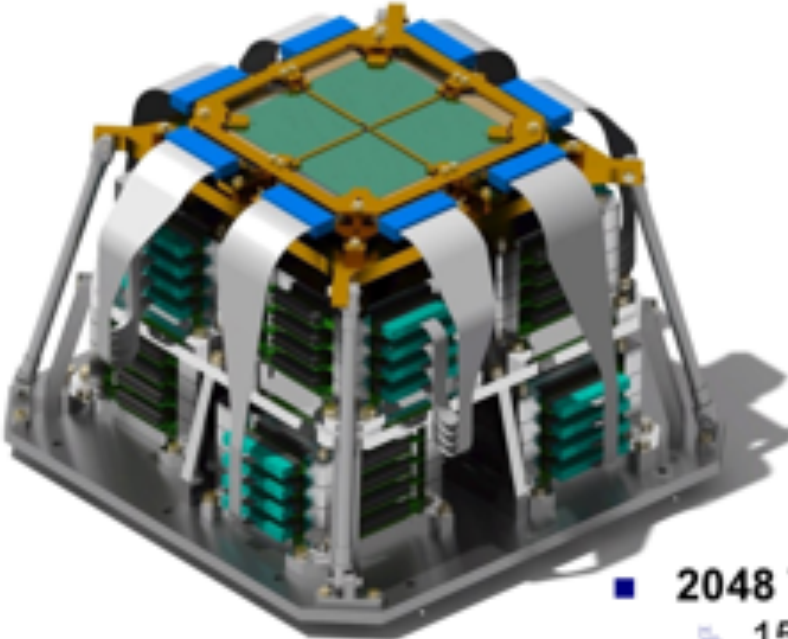
Lab	Responsibilities
APC	Coordination, cold readout, TES tests
CSNSM	NbSi, microfabrication, solid state physics
C2N	Microfabrication facility
IRAP	Warm readout

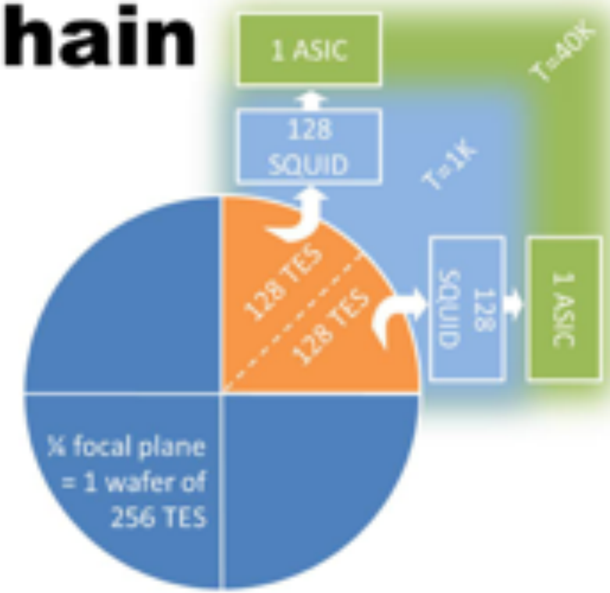


- Original points:
  - NbSi as thermal sensor
  - Cold SiGe ASIC to control the multiplexing
- CNES and CNRS funding
- Application to QUBIC

by Michel Piat at APC

QUBIC detection chain

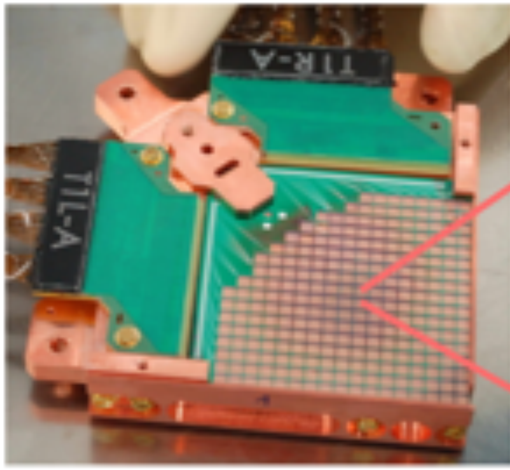




- **2048 TESs NbSi** (1024 per focal plane)
  - 150GHz and 220GHz
  - 300mK base temperature
  - NEP=5.10^{-17}W.Hz$^{-0.5}$ at 150GHz
- **TDM multiplexing with 128 mux factor**
  - 2048 SQUIDs at 1K
  - SiGe ASIC v3 at 40K
    - Capacitive SQUIDs biasing

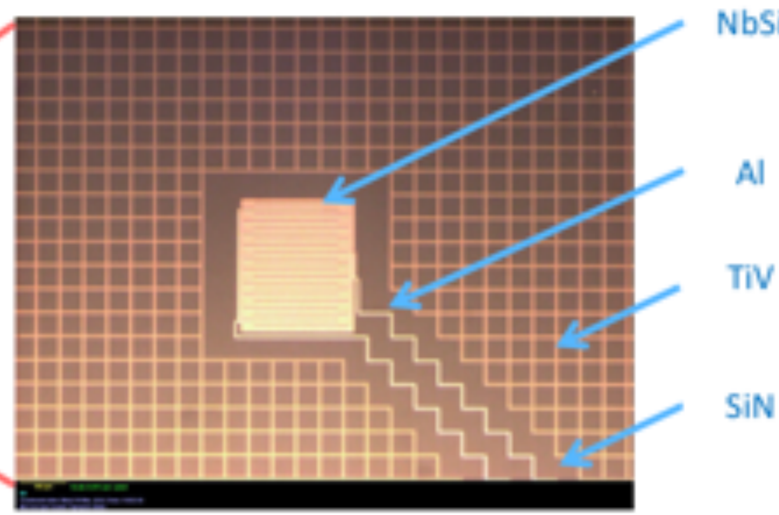
by Michel Piat at APC

QUBIC detectors: filled array

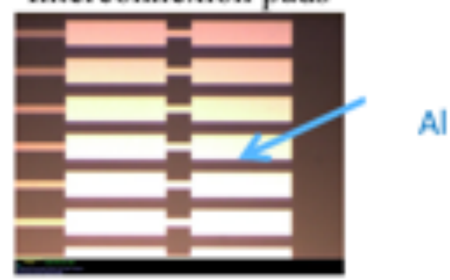


Substrat: SiN low-stress on 3 inches SOI

1. Al Routing Al
2. TES NbSi
3. TiV absorber
4. Al pads
5. Deep etching
6. Membrane etching
7. XeF_2 etching



Interconnexion pads

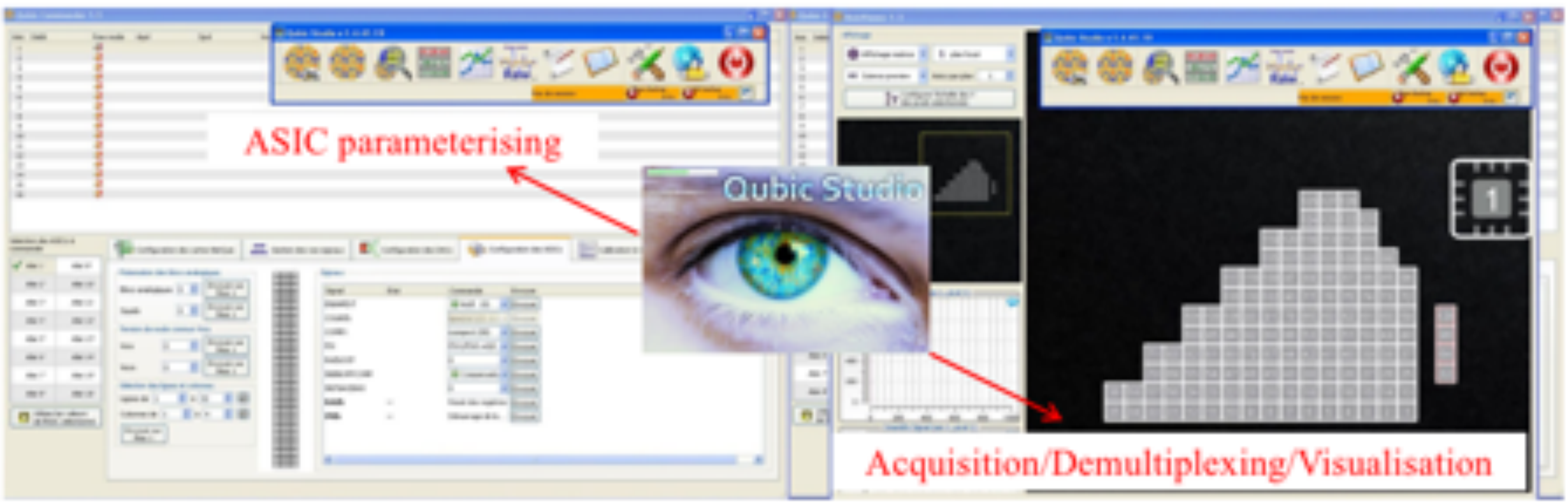


Dual band: backshort adaptation (same for the 2 bands)

Detection chain: warm readout and acquisition système

- Warm readout (4W for 128 TESs):
- FPGA
- ADC/DAC
- Serie link with ASIC
- Power supply ASIC

- Software QUBIC Studio:



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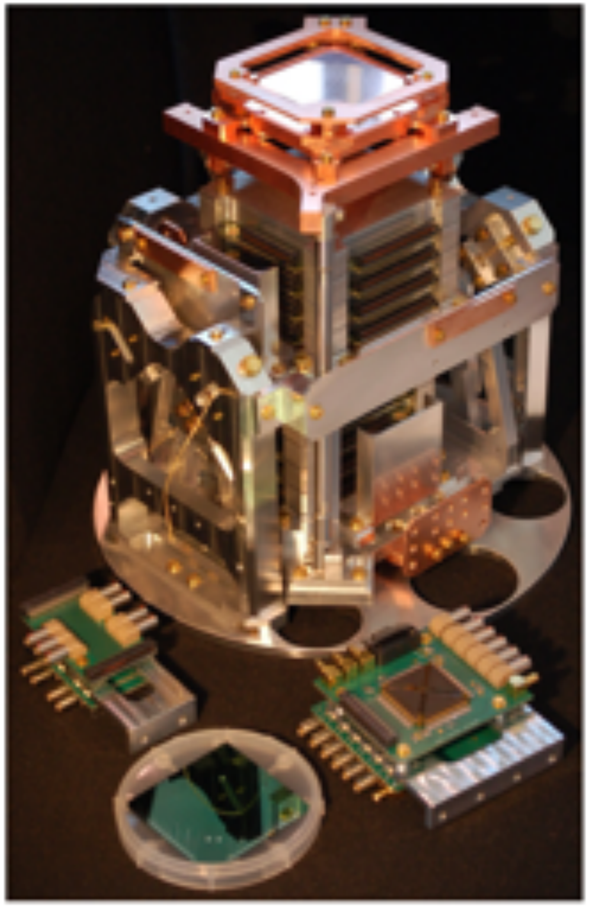
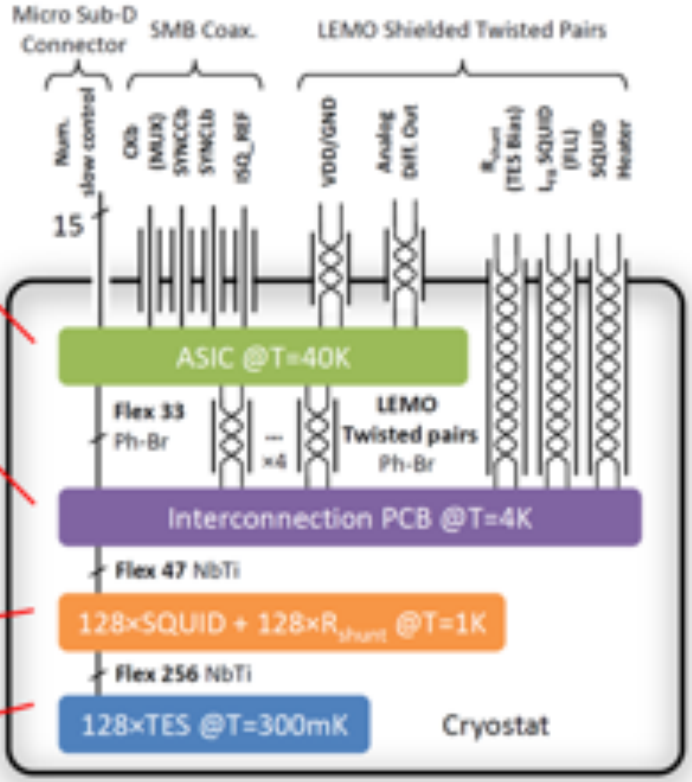
Test of ¼ focal plane in dilution



Cryostat wiring for 128 TESs readout



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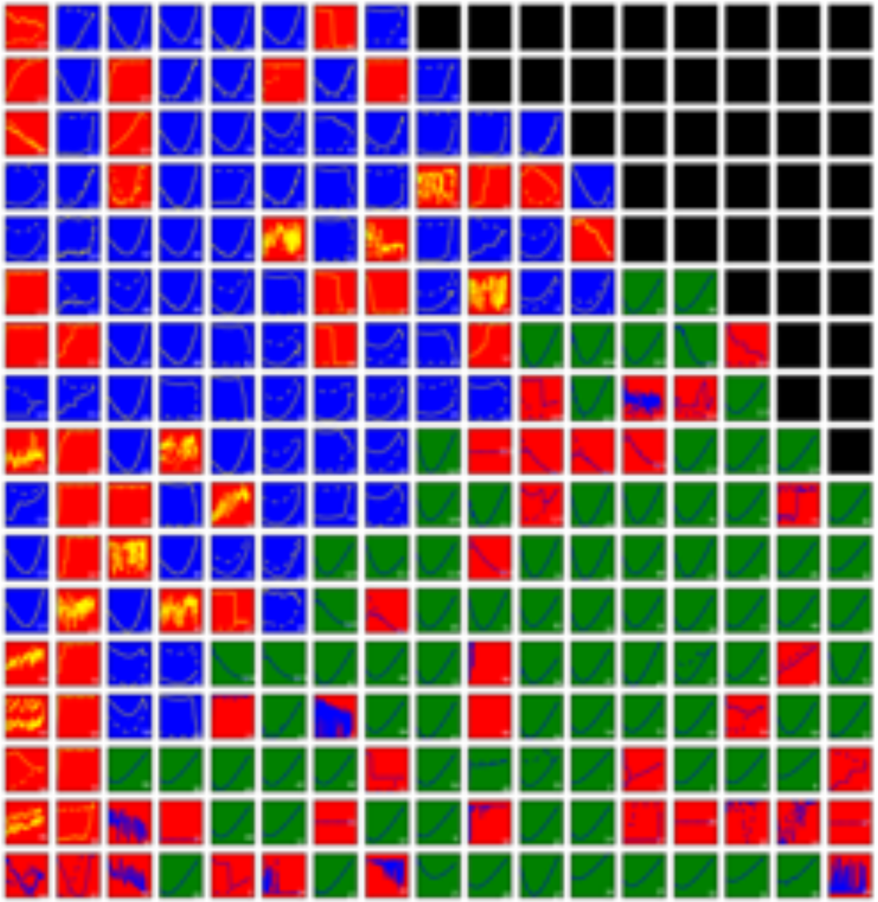
TES array characterisations (ongoing work)



- I-V curves at 300mK
  - ASIC 1
  - ASIC 2
- Automatisation of characterisation procedures
- Yield: ~70% (array P73)
  - ~20% from fabrication
  - ~10% from readout

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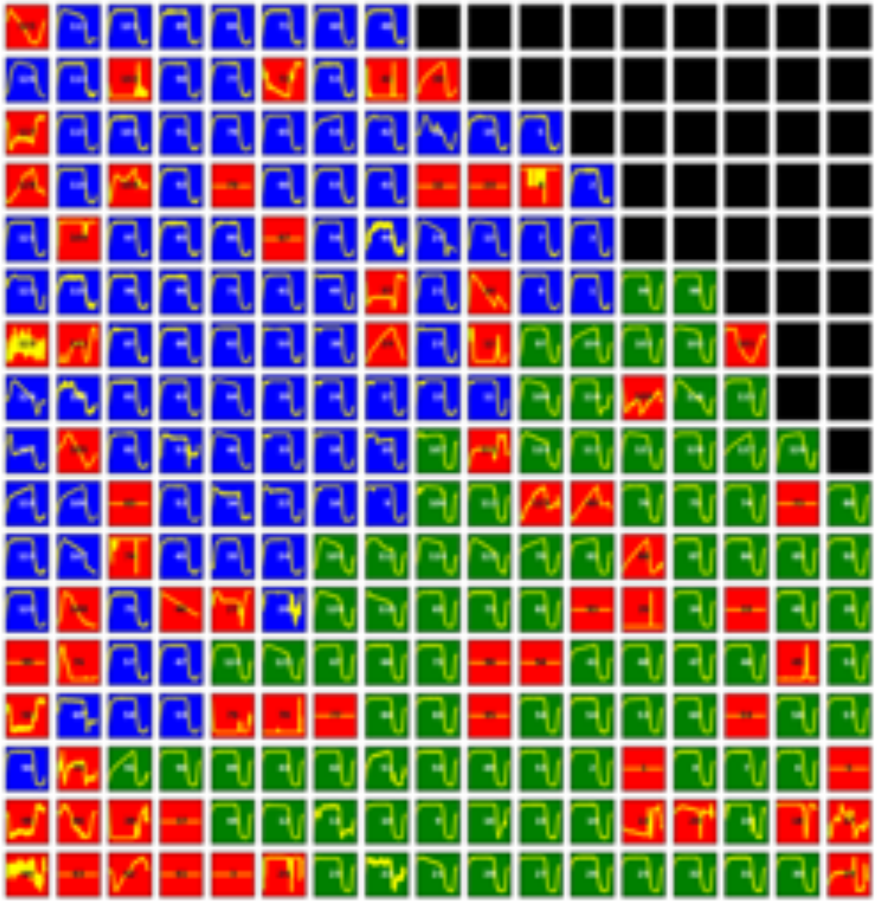
Signal from a C fiber source

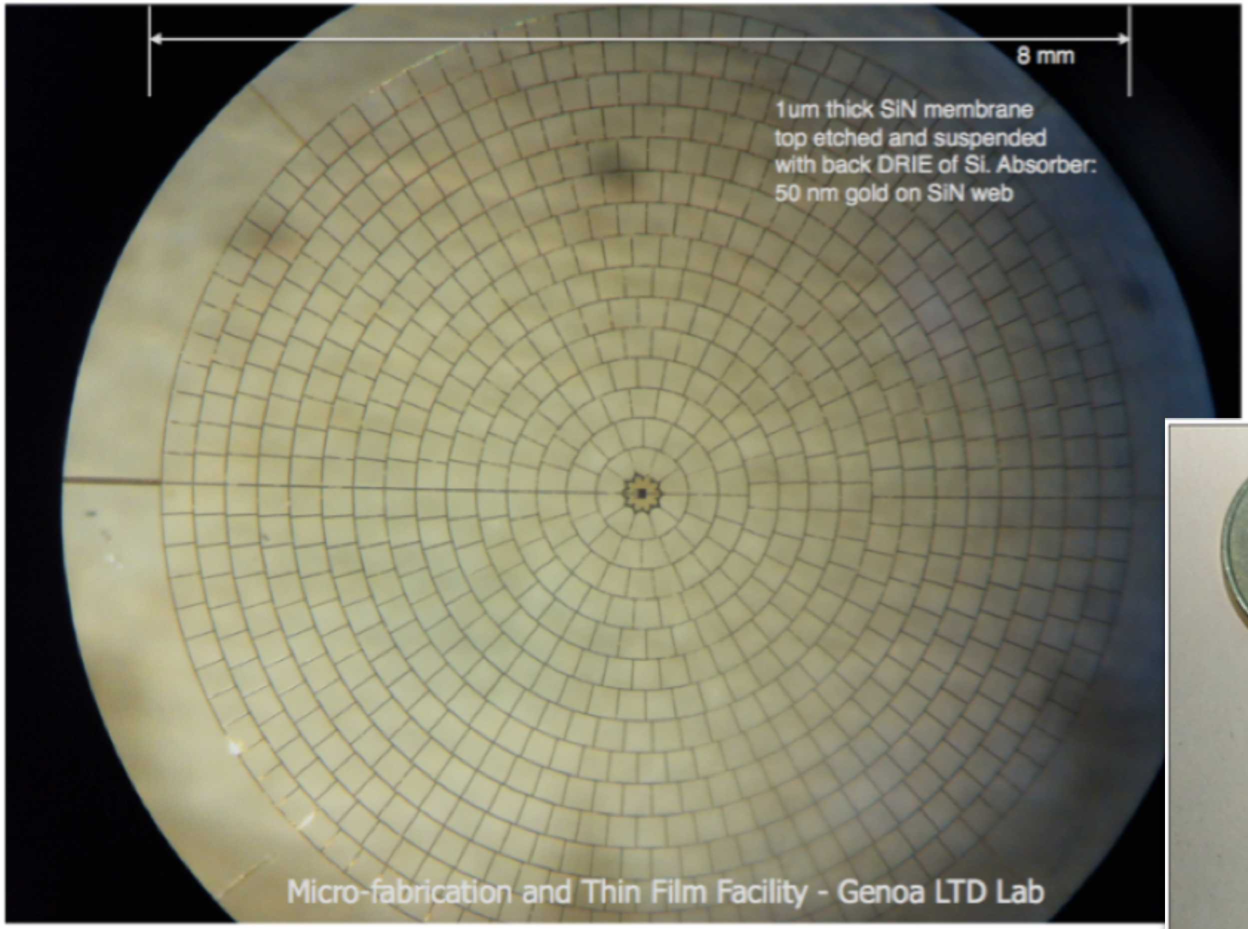


- Pulse signal on the detectors
  - ASIC 1
  - ASIC 2
- C fiber source provided by LAL
  - At 1K, in front of the array
- Other measurements: glitchs with Am source

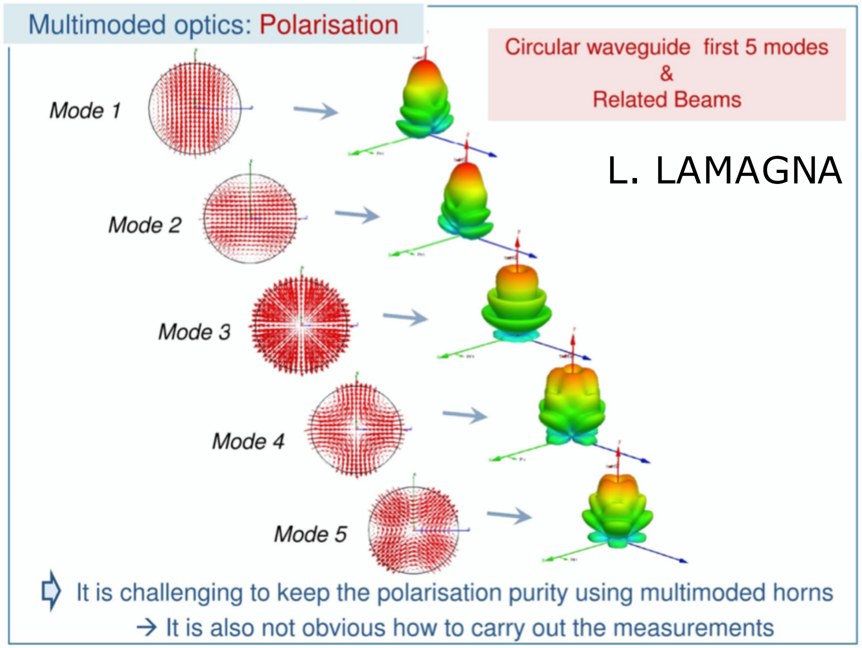
by Michel Piat at APC

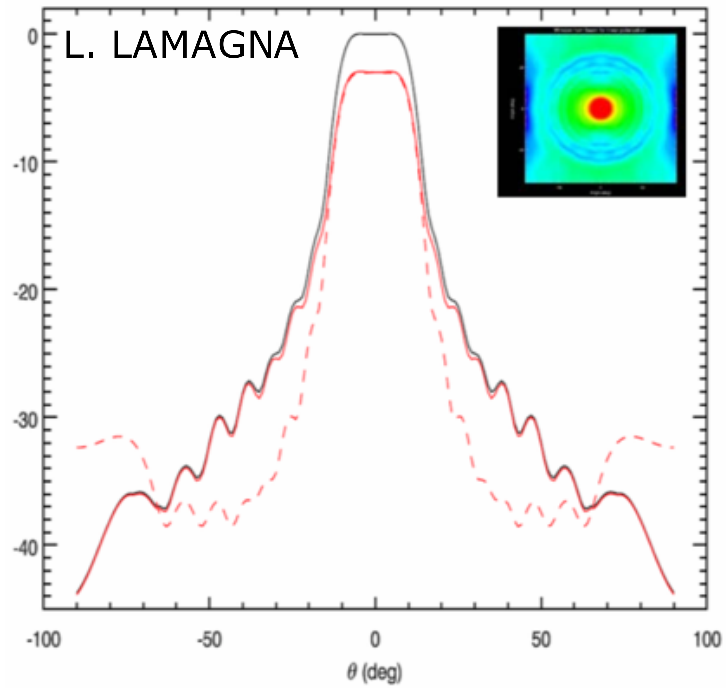
TES Large Area Bolomter for LSPE

Bolometers: starting point (Genova)



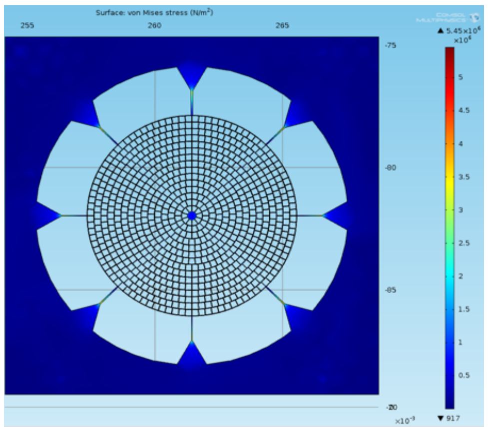
- LSPE based on Multi-Mode detection: Bolometers must couples with several tents of cavity modes (P.de Bernardis)
- This is the motivations of a such large area
- Expected performance of comparable experiment with 10^3 single mode detector
- Top flat beam is within the required angular resolution of LSPE

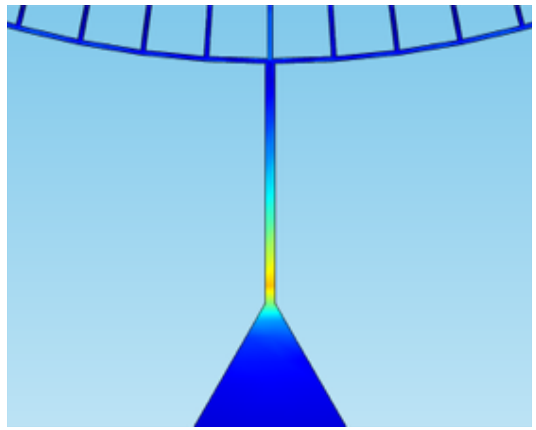


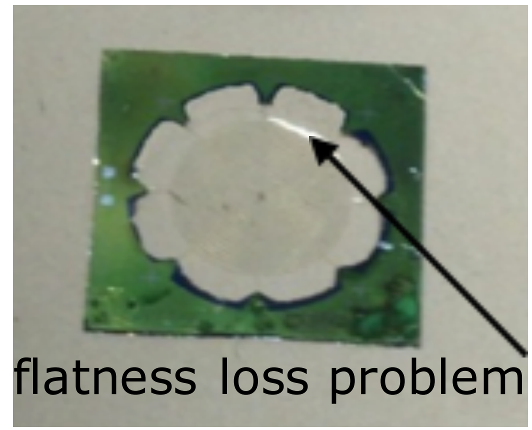


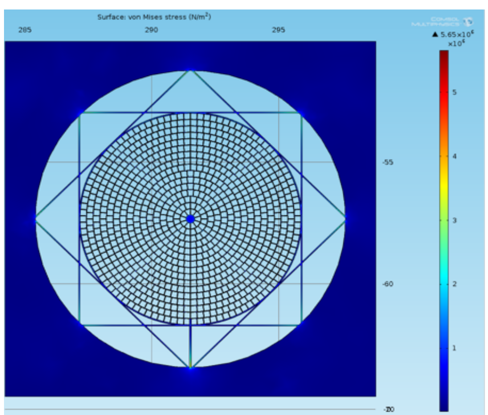
Design Review and upgrade

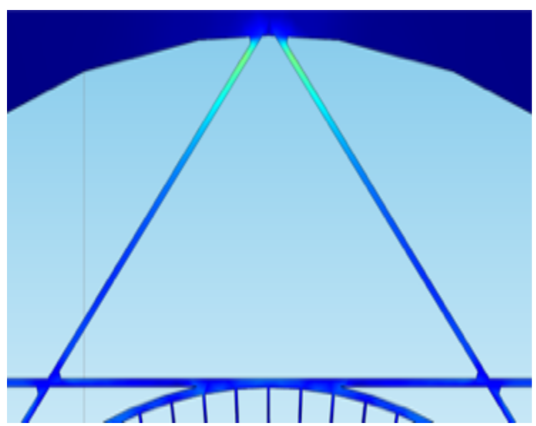
- Largest spiderweb bolometers even built: Metal film-SiN stress release → wavy shape at the edges
- Reduction of von Mises stress at the supporting beam → more than a factor 3











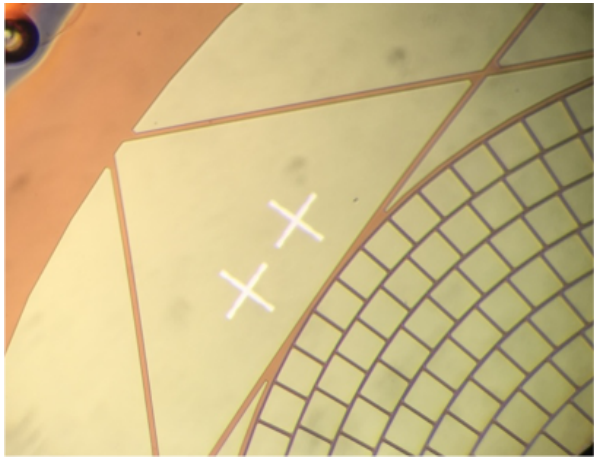
Design Review and upgrade

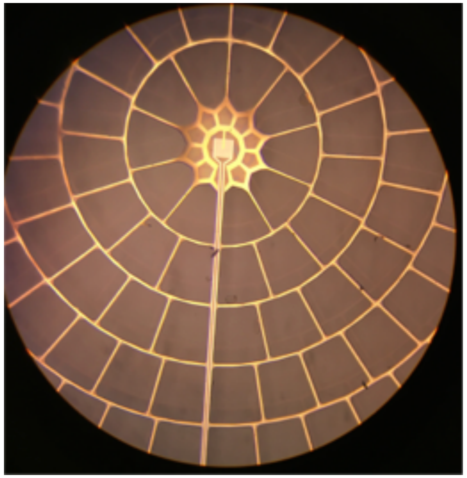
1. TES: TiAu,

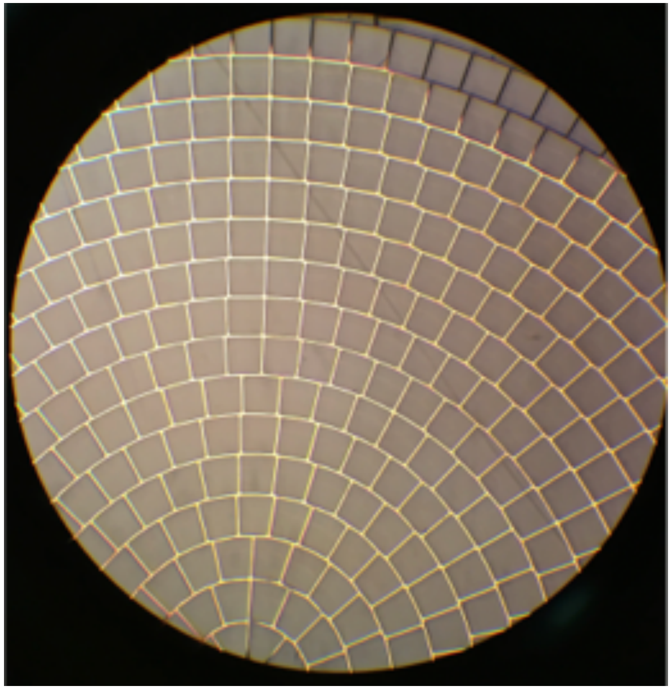
   Ti: Tc(0.4-0.6 K) depends process T profile (issue fixed)

   MoAu: unsatisfactory results

1. New Wiring: Nb better than Al
2. New mechanical structure (wavy almost negligible)
3. Fabrication and micro-etching recently switched to RIE-ICP for BOSH process

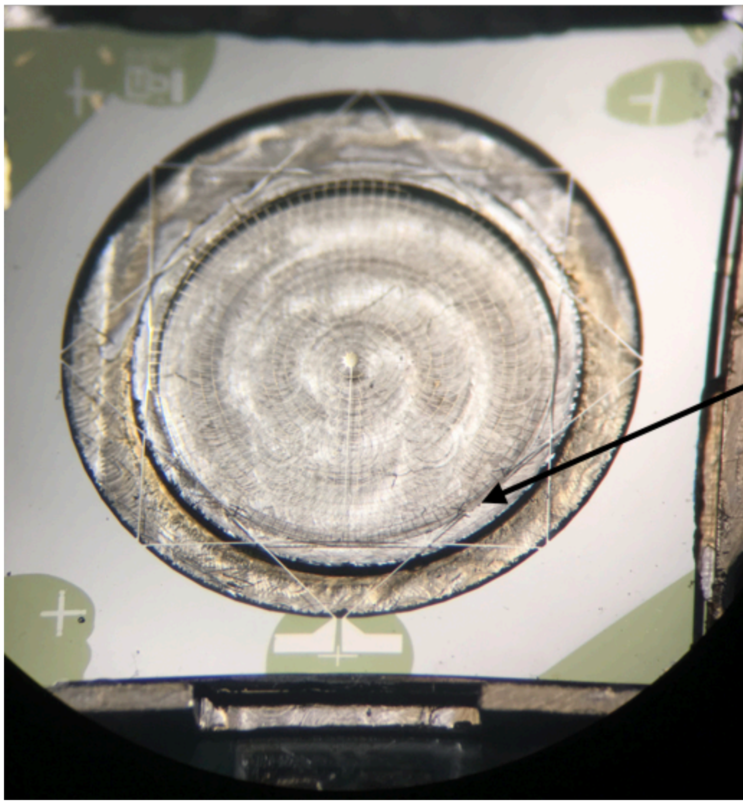


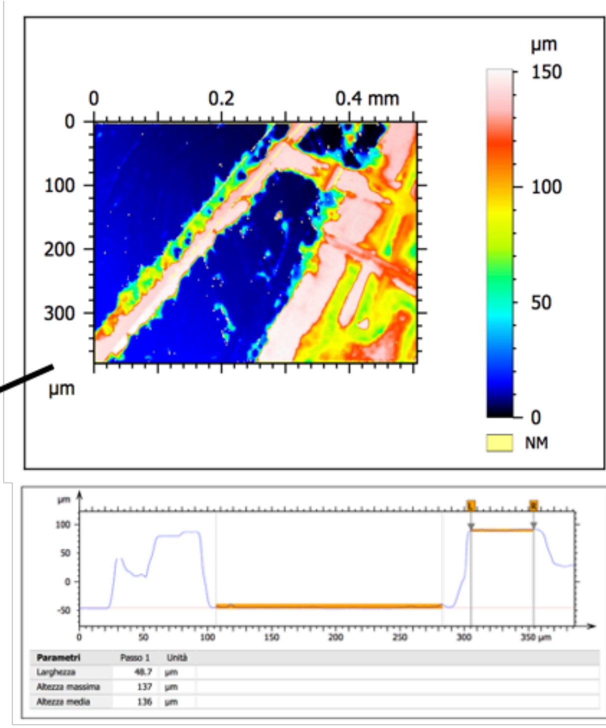




1. New Bolometer mounted in the cavity

2. Horn and Focal Plane (P. De Bernardis)

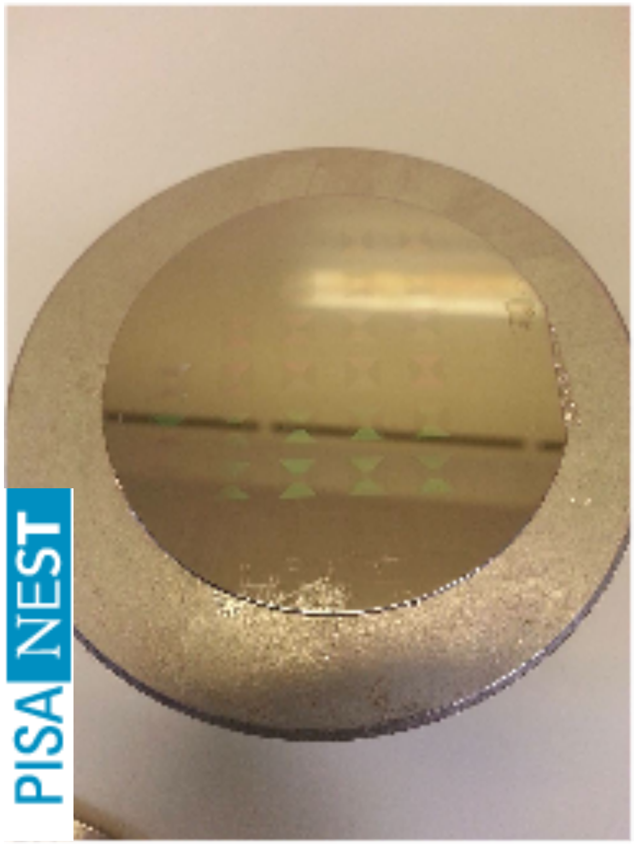


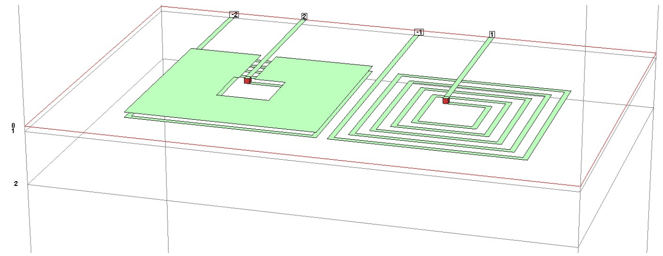


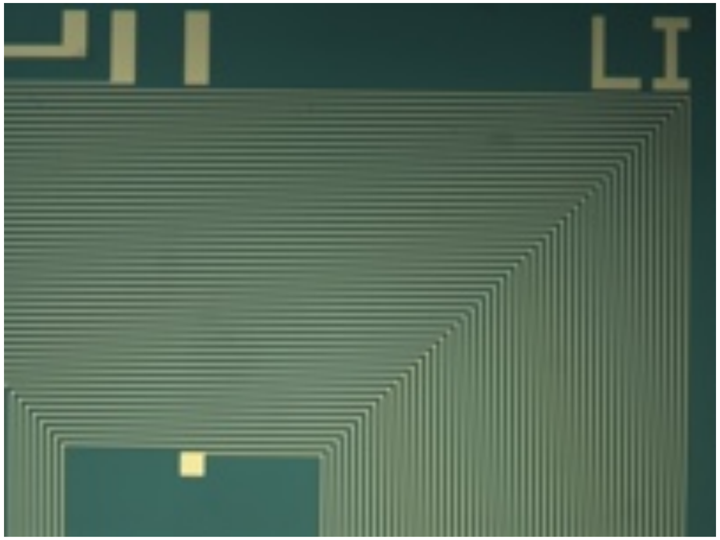
Parametri	Passo 1	Unità
Larghezza	48.7	μm
Altezza massima	137	μm
Altezza media	136	μm

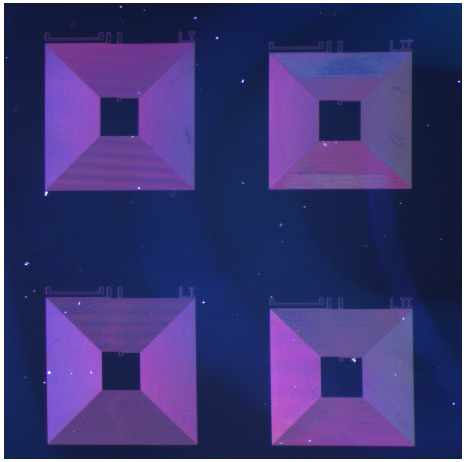
Custom LC circuits for FDM resonators

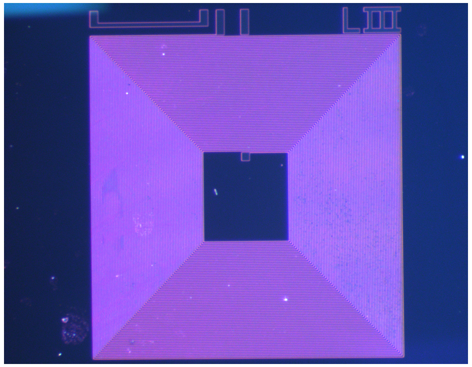
- Niobium inductors produced on 2” Si wafer
- Designed, simulated and tested at INFN Pisa- Fabricated at CNR-NANO PISA and INFN PISA





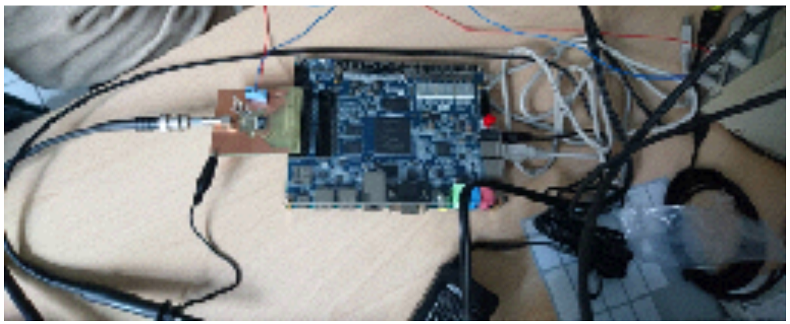


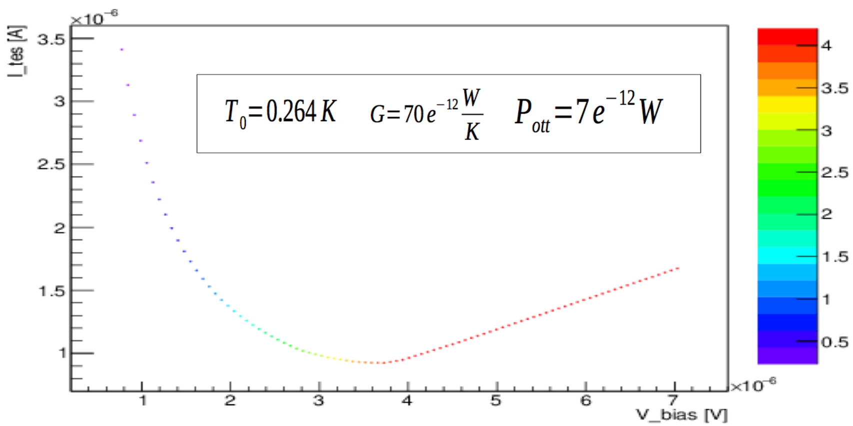


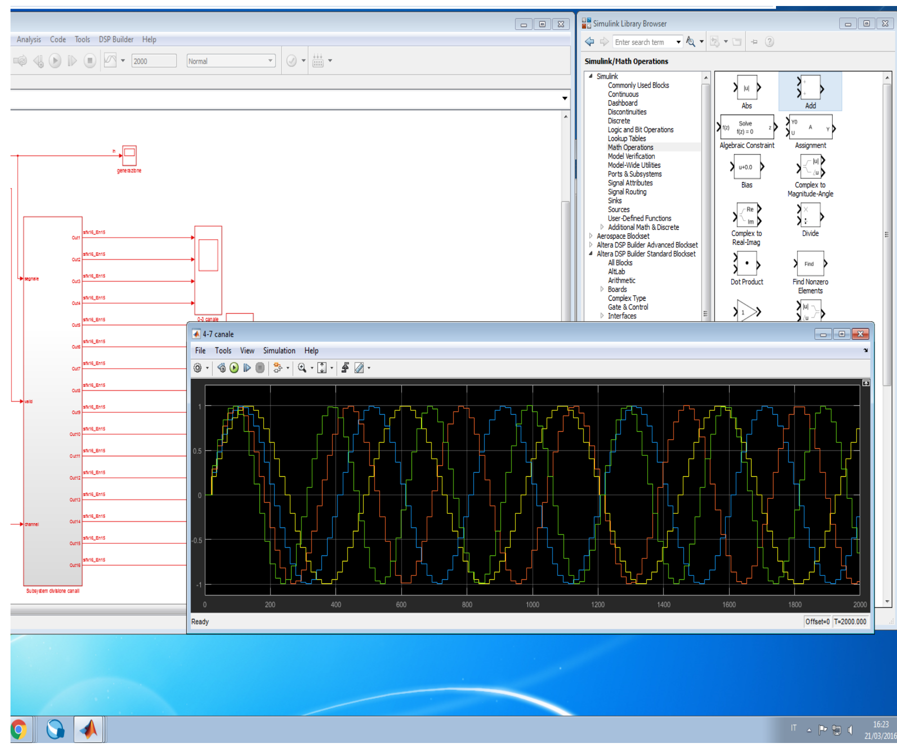


Custom LC circuits for FDM resonators

- FPGA controls the carrier frequencies generation and de-MUX
- Provide operating set-point tuning of TES bolometers
- Firmware test done with Altera CicloneV FPGA for DAC/Carrier gen.
- Foreseen migration to MicroSemi SmartFusion2

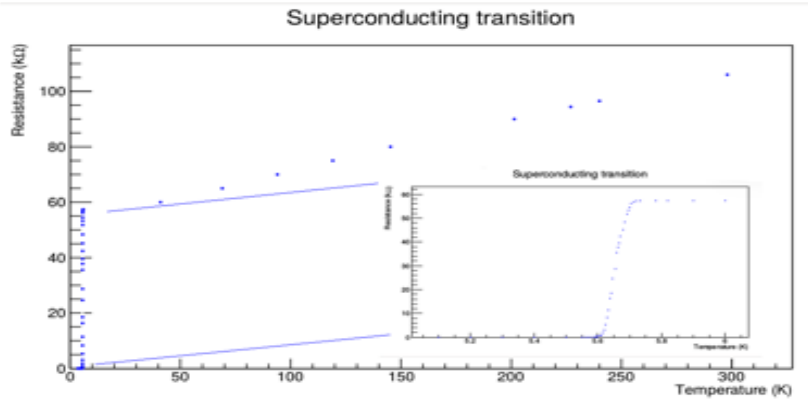


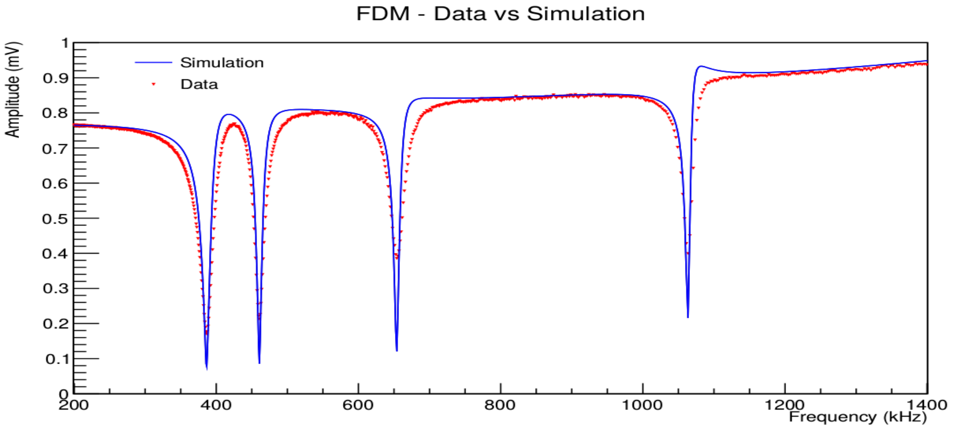


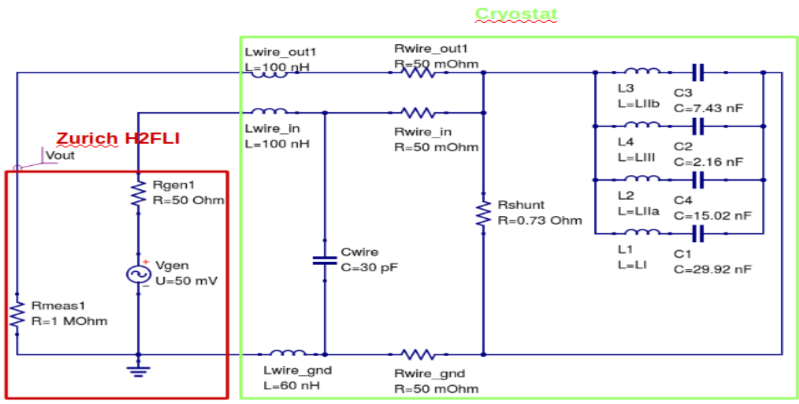


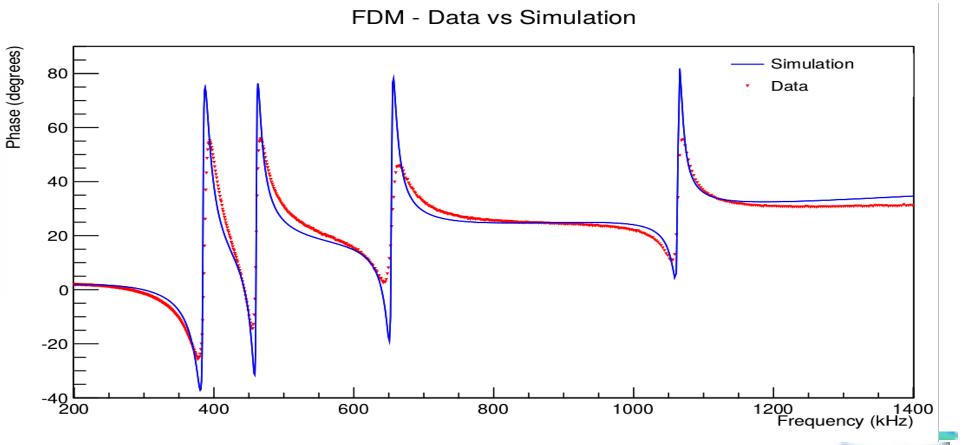
Custom LC circuits for FDM resonators

- Pack 16 carriers in 0.2 -2 MHz frequency band for the LSPE bolometers
- Nb quality test: Tc=5.6 K , RRR=2
- 4-resonator test at 4.2: amplitude and phase (data vs simulation)









Future Developments (Funds by ASI & INFN)

1. INFN funds assed for LSPE Bolometer
2. ASI-INFN funds (0.4M€ over a total 1M€) specifically for Bolometer developments
3. Goals:
   a. Antenna Coupled Bolometers
   b. High Multiplicity GHz FDM (under study for Neutrino Project with NIST)
4. R&D:
   a. Planar Antennas (multicrhoic and polarization saving)
   b. HF Striplines and Filters
   c. Small TES bolometer (10^{-2} um)
   d. High multiplicity FDM (several → 10^3)
5. Teaming up with Uni. Trento - TIFPA and FBK
   a. Antenna design
   b. HF striplines and Filters (FBK)
   c. Large scale production (FBK)