Developments of silicon based low temperature detectors

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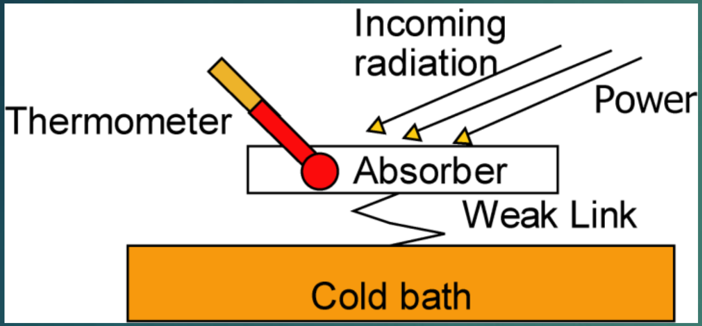
Outline

- Overview of Genoa Low temperature detector group activity
  - HOLMES ERC advanced grant (Idea and Goals)
  - ATHENA x-ray space mission
  - Cosmic Microwave Background spider web detector preliminary development
- A possible contribution to electronic coupling

Thermal detectors: bolometer & calorimeter

Basic idea of this detector

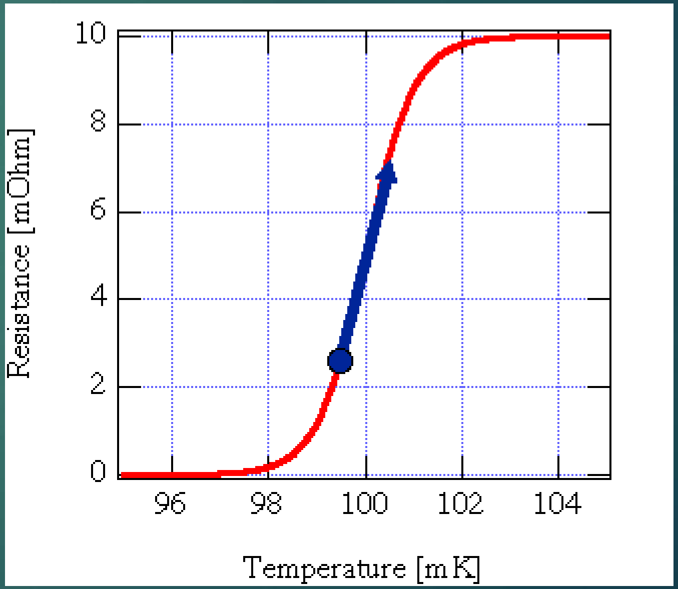


Incoming Radiation (photons, charged particle) or decay of implanted isotopes heats the absorber.

We detect temperature variation.

TES as thermometer

The thermometric element is a superconductor thin film used across its critical temperature

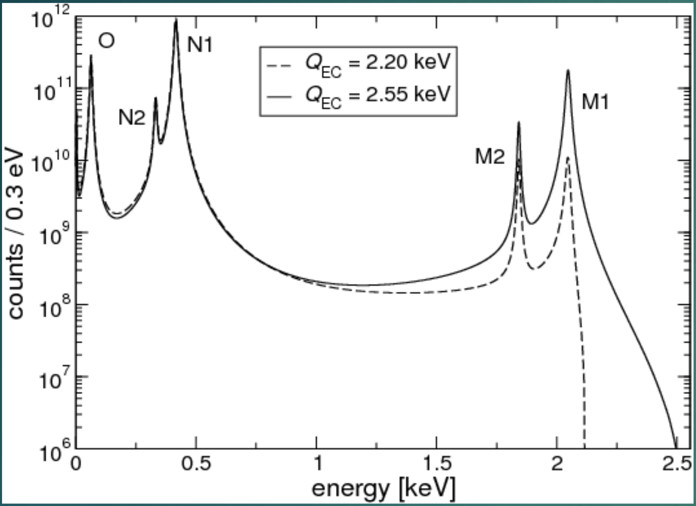


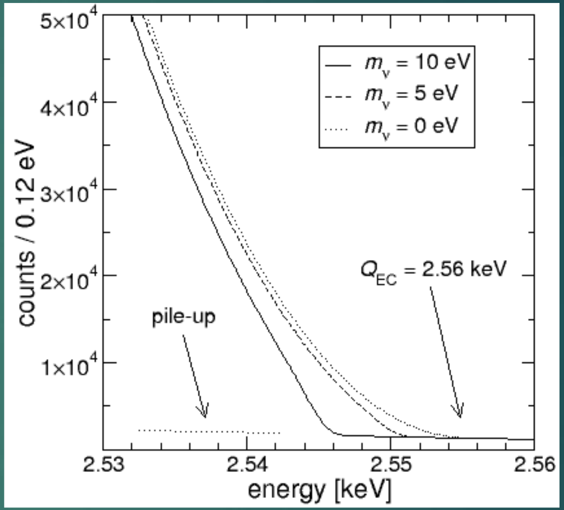
$$\frac{T_0}{R_0}\frac{dR}{dT} > 50$$

In collaboration with

HOLMES

The Electron Capture Decay of ^{163}Ho to Measure the Electron Neutrino Mass with sub-eV Sensitivity



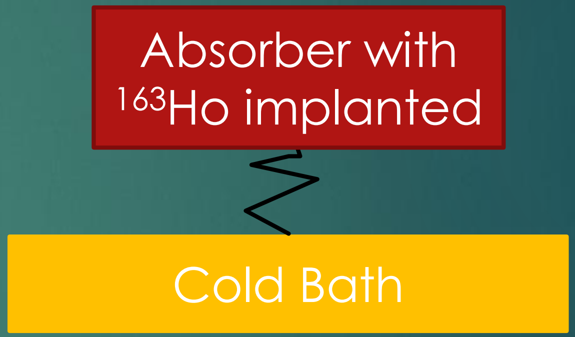


- A calorimeter can detect all energy of the decay process except neutrino energy
- The deviation from of the spectrum Breit-Wigner at the end point is due to the ν mass

In collaboration with

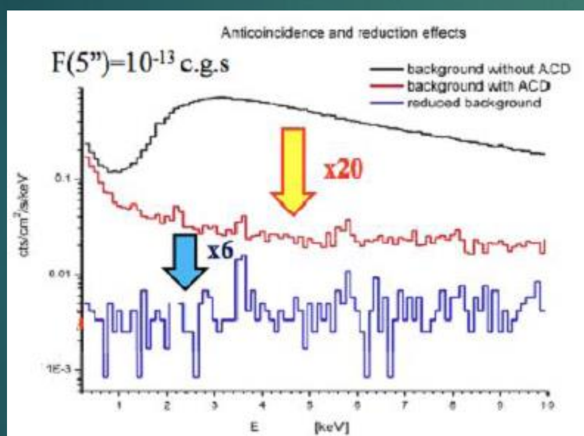
HOLMES Objectives

- 1000 detectors based on TES in one array multiplexed
- 1-3 years of data take
- 300 Bq of activity for each detector
- $\Delta E \sim 1$eV
- Time resolution 1 μs

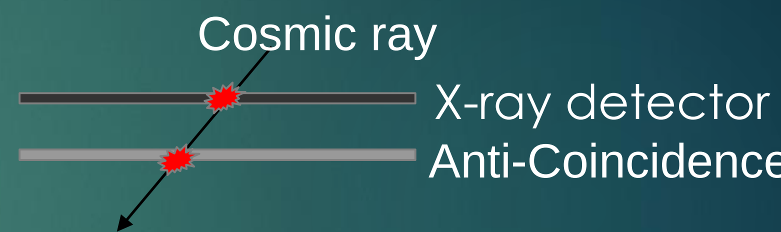


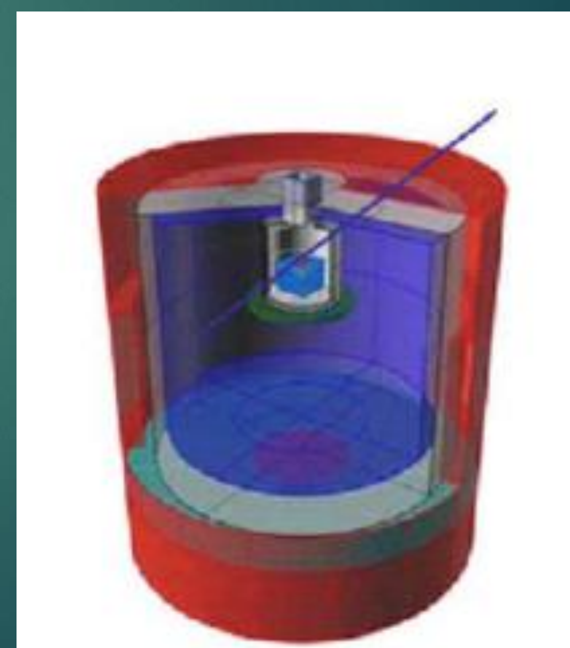
Anti-Coincidence detector for ATHENA x-ray space mission

- Cosmic rays can excite x-ray detectors, producing a large background

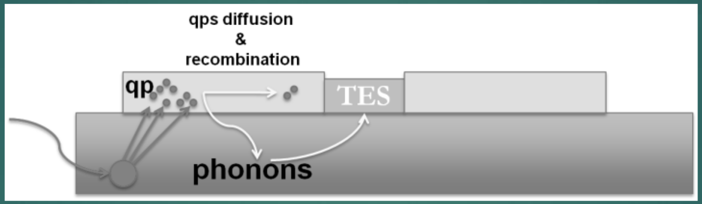


A factor 20 can be performed just using a Anti-Coincidence



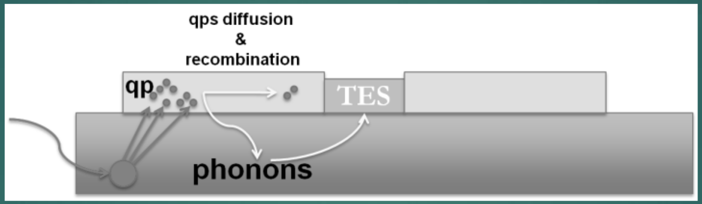


Cryogenic Anti-Coincident concepts



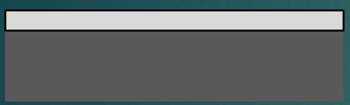
- The absorber is the Silicon substrate
- Charged particles produce phonons in silicon

Cryogenic Anti-Coincident concepts



- The absorber is the Silicon substrate
- Superconducting thin film is used as collector to increase the rise time
- Charged particles produce phonons in silicon
- Phonons broke Cooper pairs. Quasi particle are collected to the TES

Fabrication process 1: TES & collector



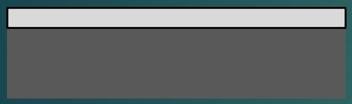
Ir thin film grown (320 nm) by PLD on silicon wafer

Positive Photolithography

Dry etching by ion milling

Al collectors and wiring by negative photolithography and lift-off process (450 nm)

Fabrication process 1: TES & collector



Ir thin film grown (320 nm) by PLD on silicon wafer

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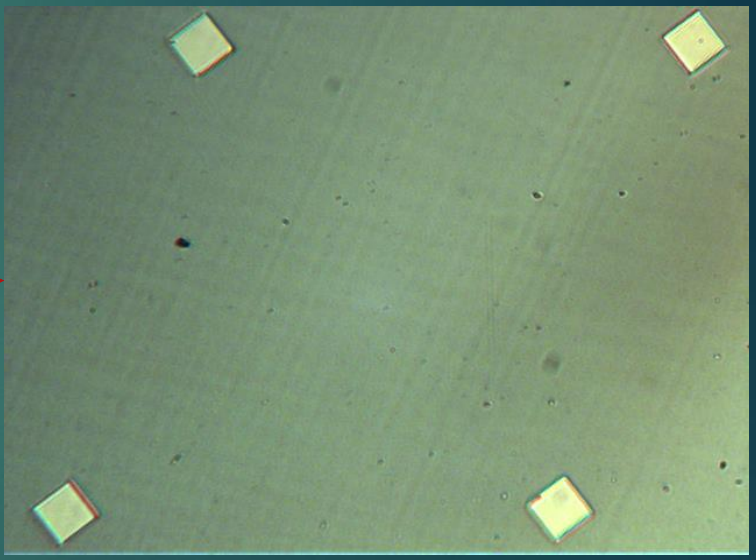
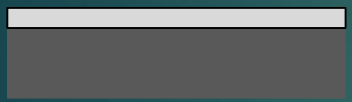
Al collectors and wiring by negative photolithography and lift-off process (450 nm)

65 TES 100x100 μm
on 10x10 mm square chip



Fabrication process 1: TES & collector



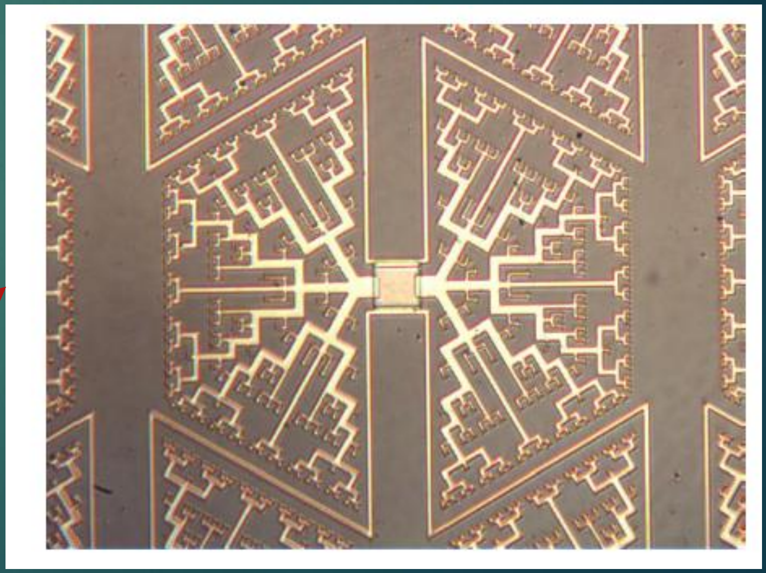
Ir thin film grown (320 nm) by PLD on silicon wafer

Positive Photolithography

Dry etching by ion milling

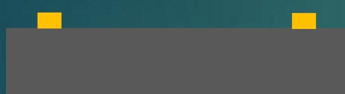
Al collectors and wiring by negative photolithography and lift-off process (450 nm)

65 TES + Al Collectors
on 10x10 mm square chip
Parallel wired

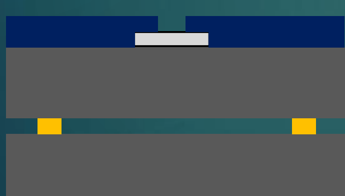


Fabrication process 2: Thermal buffer

A second silicon wafer was used as thermal buffer

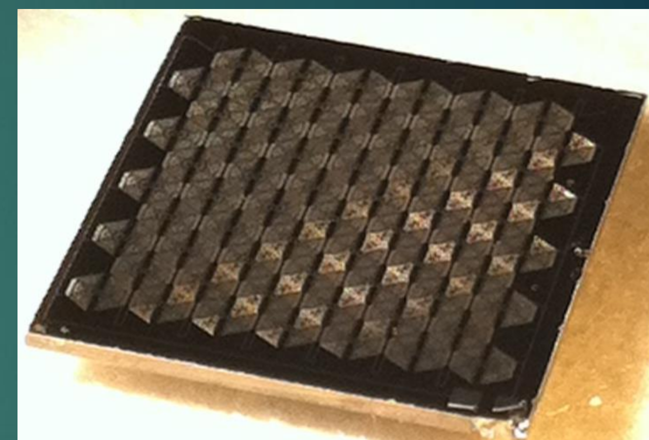


4 pillars (50 µm high) was built using negative photolithography and permanent SU-8 photoresist



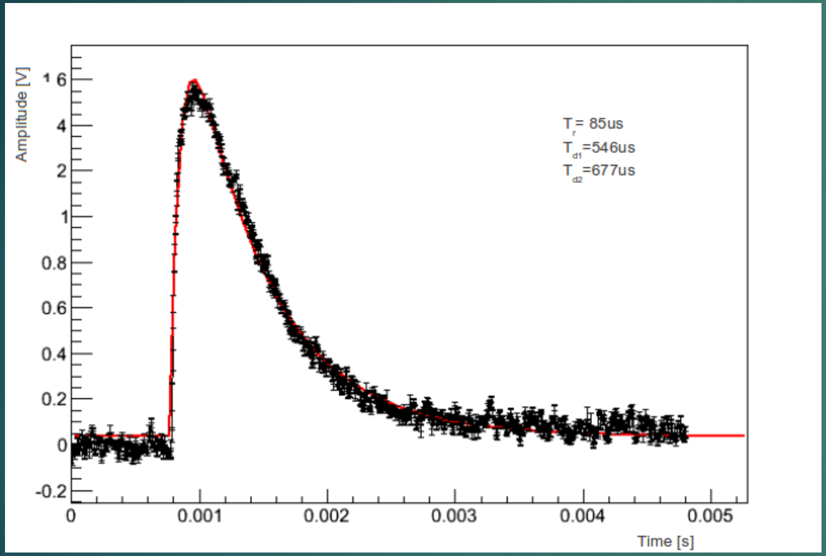
The 2 wafers were jointed

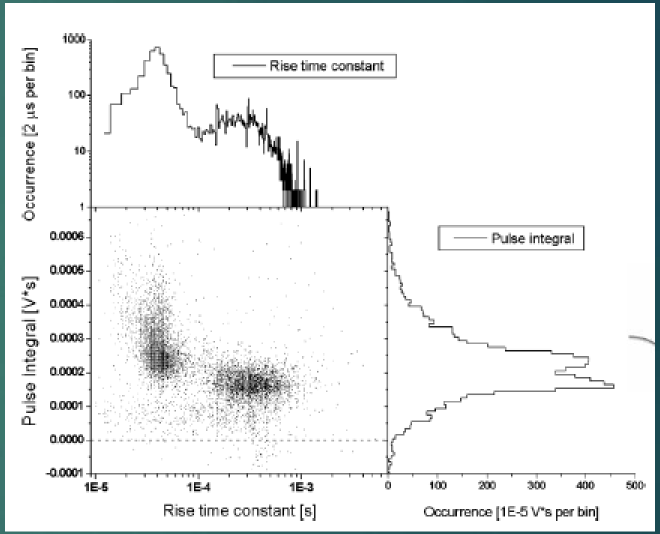
Pillars are the thermal weak link ~ $4x10^{-5}$ W/K



The device at work

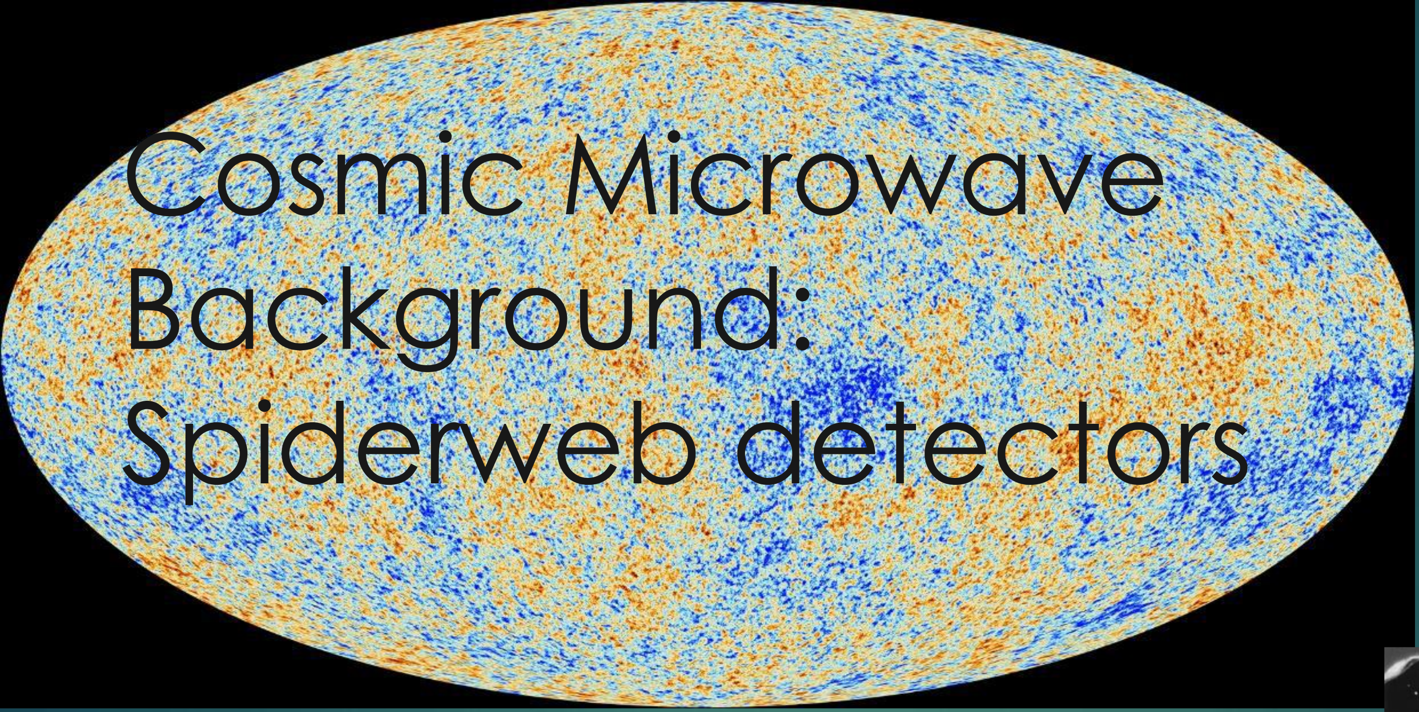
Response to 60 keV γ-ray from ^{241}Am source @ 120 mK

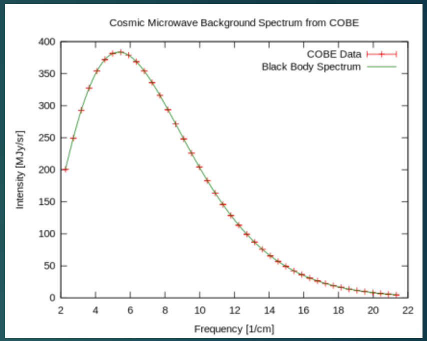




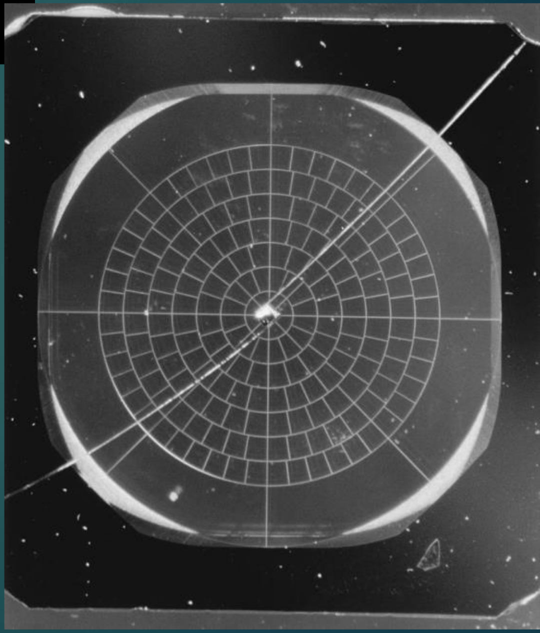
Rise Time	Decay Time
85 µs	680 µs

Cosmic Microwave Background: Spiderweb detectors





- Blackbody at 2.7 K → microwaves with λ ~ 1 mm
- The cosmic rays coming from the space are a problem also for a microwave bolometer…



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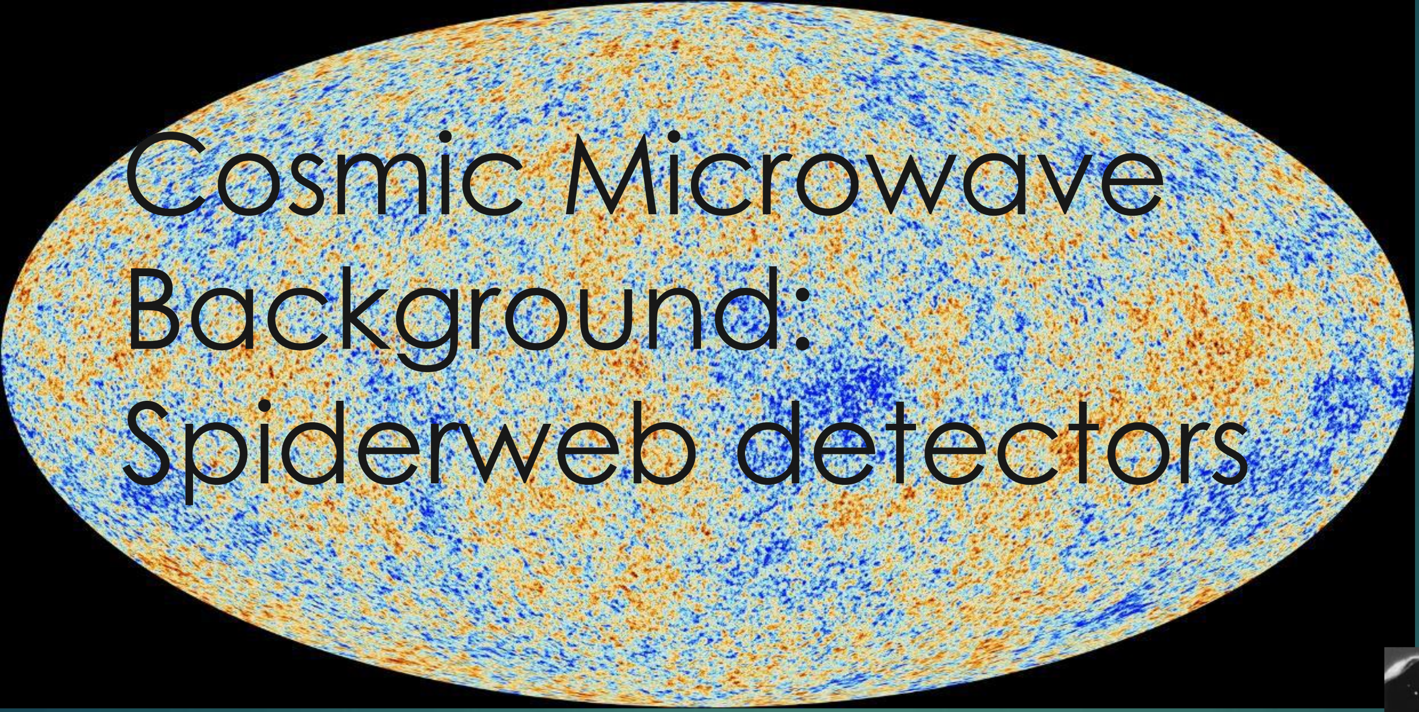
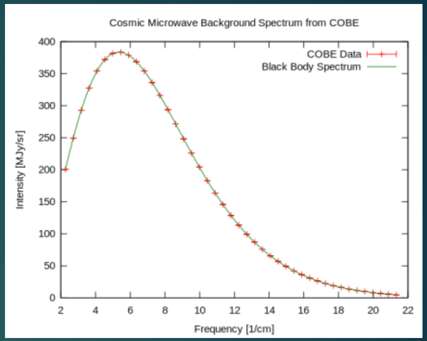
Cosmic Microwave Background: Spiderweb detectors

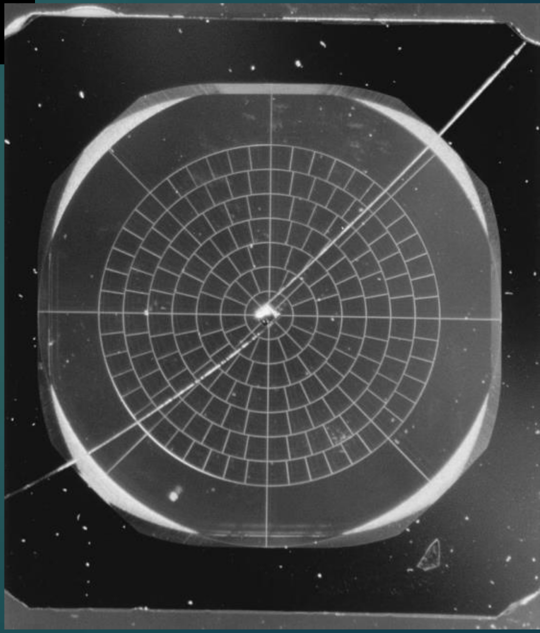




- Blackbody at 2.7 K → microwaves with λ ~ 1 mm
- The cosmic rays coming from the space are a problem also for a microwave bolometer…

…A grid with a step smaller than λ\4 can be equivalent to a filled disk to detect a RF signal.

But reduce strongly the surface exposed to the cosmic ray



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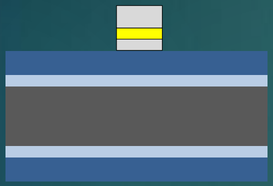
Fabrication Process 1: metals deposition

Negative Photolithography, e-beam metal evaporation, Lift-off process

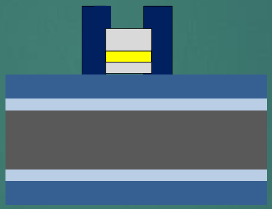
Starting from a silicon wafer covered

- 1 μm Si_3N_4
- 0.5 μm SiO_2

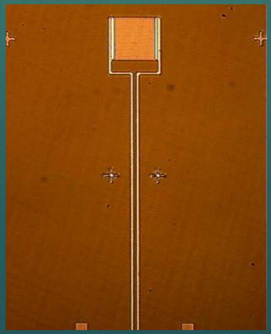


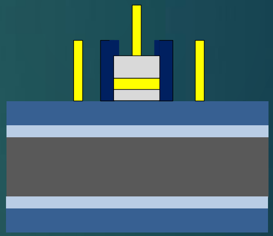
TES deposition

Ti 5 nm
Au 4 nm
Ti 38 nm



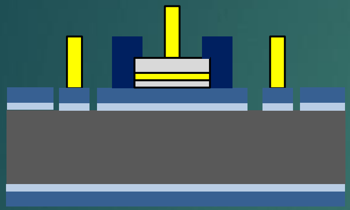
Aluminium wiring deposition



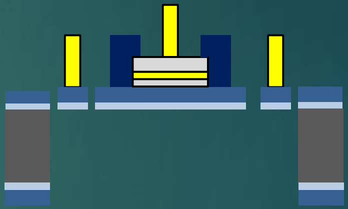


Au absorber deposition

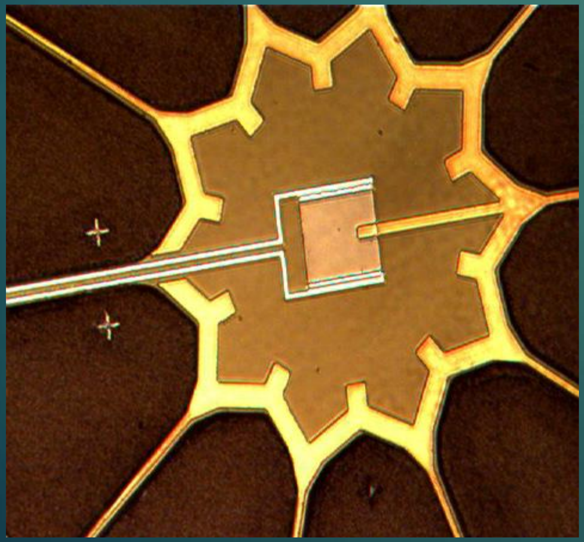
Fabrication Process 2: Etching

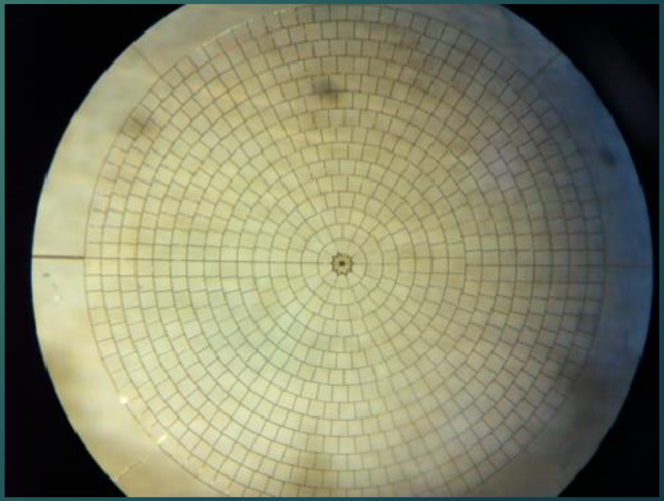


Positive photolithography and RIE CF_4+ O_2 etching

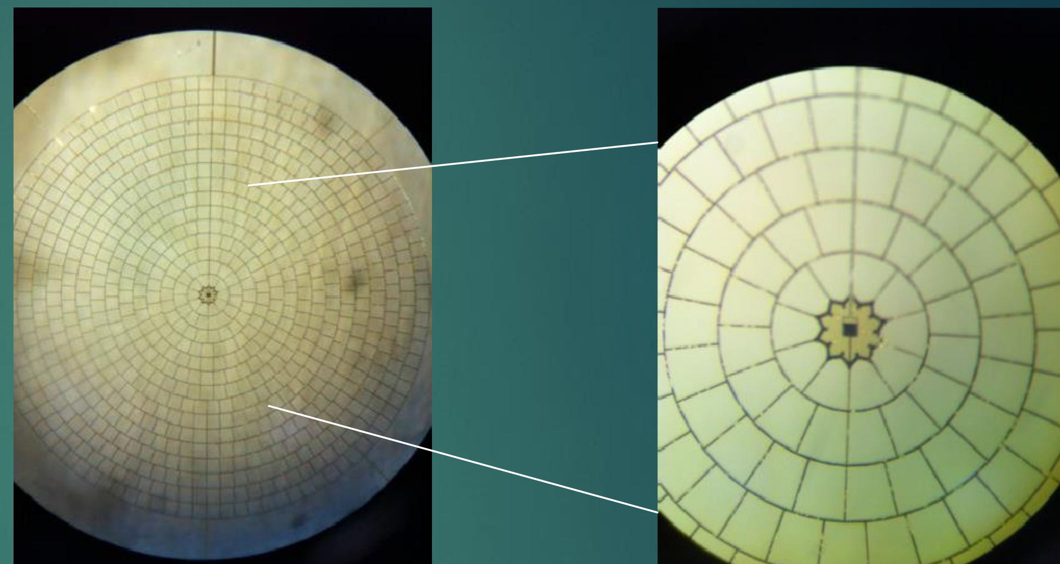


RIE back wafer etching with SF_6+O_2 and suspension of spiderweb structure





The final object



Spiderweb diameter 8 mm

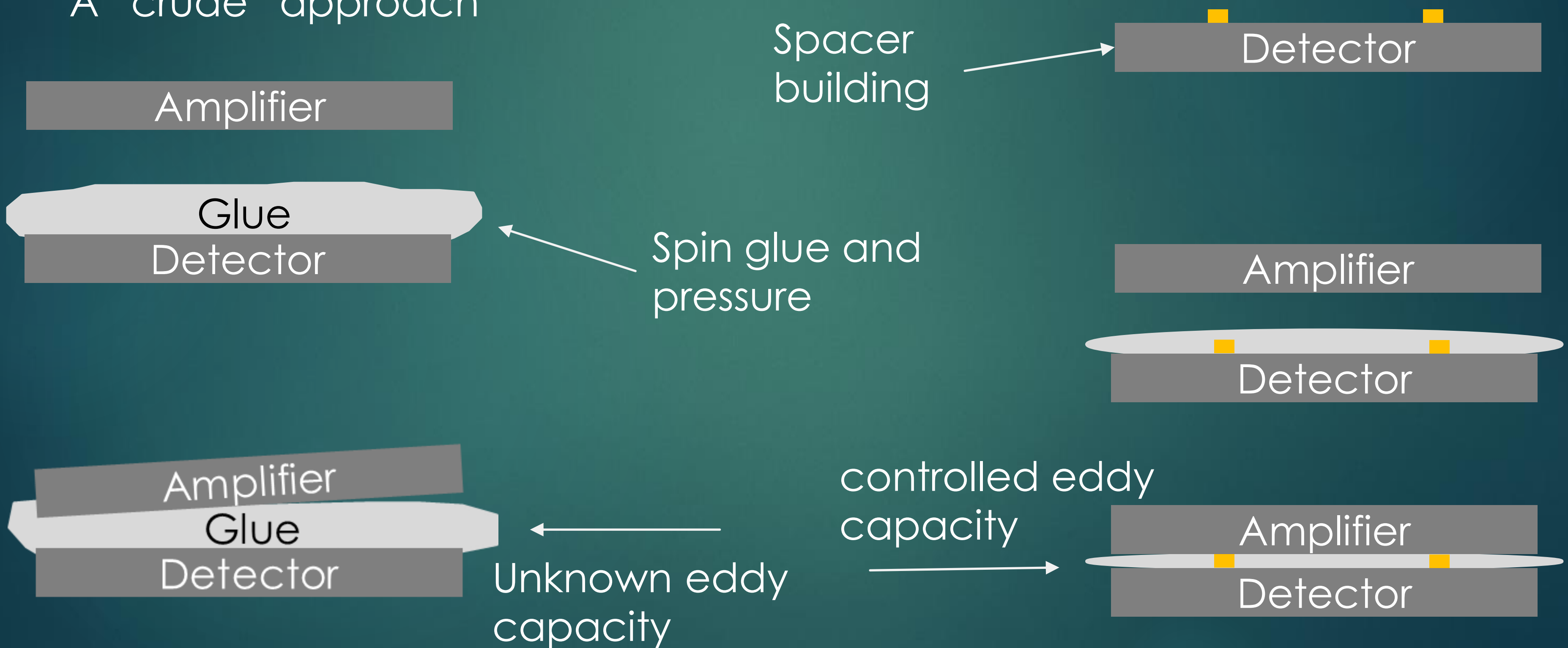
Total free standing area 9 mm

Square chip side 15 mm

Possible contribution of electronic coupling

Provide uniform capacitive coupling between amplifier and detector chip and safe gluing at the same time.

A “crude” approach



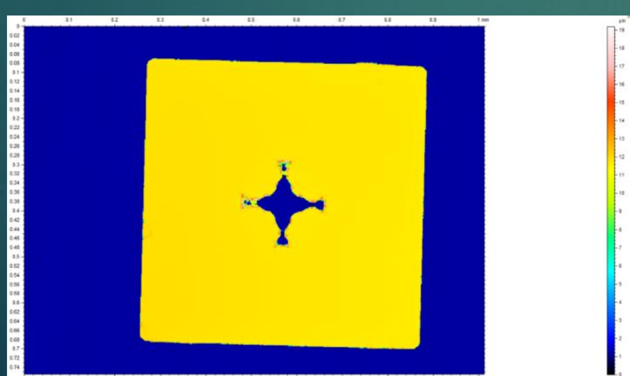
Pillars built with our micromachining facility

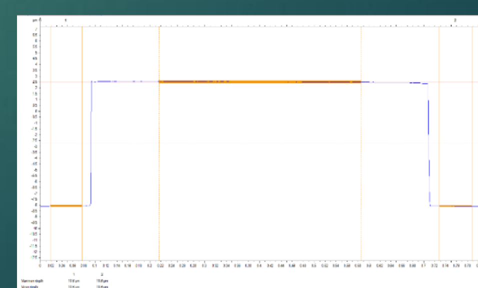
Preliminary test with already available materials (old SU-8 resit, litho-mask and silicon wafers)

Pillar 1	5.92
Pillar 2	6.07
Pillar 3	5.92
Pillar 4	5.92

< 0.1 μm height error on a single pilar

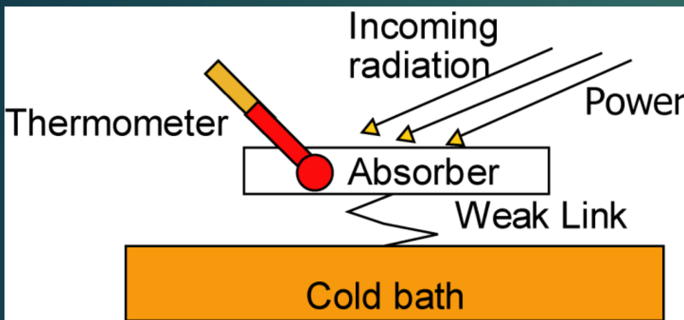
4 mm distance between two pillars

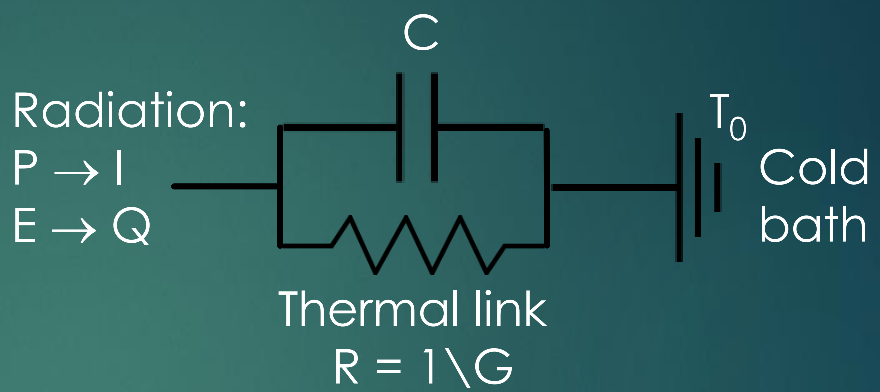




Thank you for attention

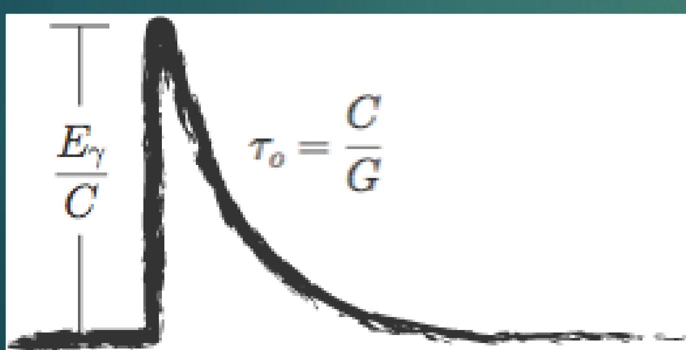
Bolometers & Calorimeters

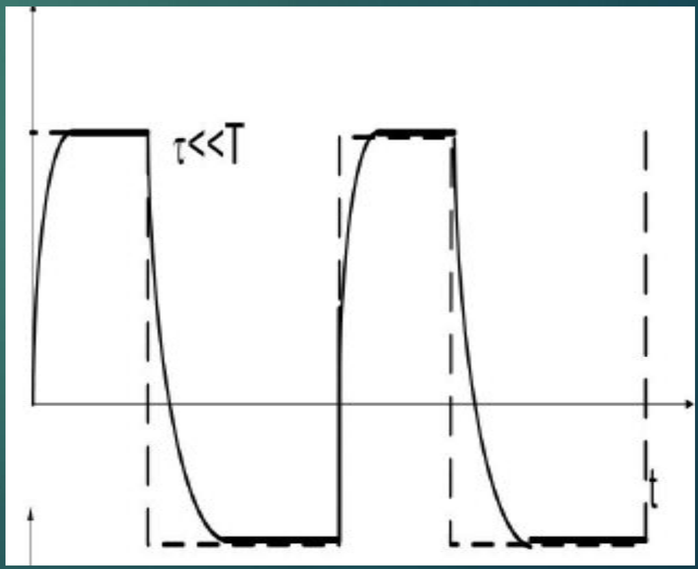




Calorimeter $\tau_0 >> T$

Bolometer $\tau_0 << T$

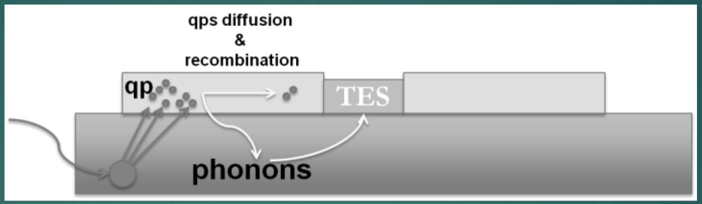




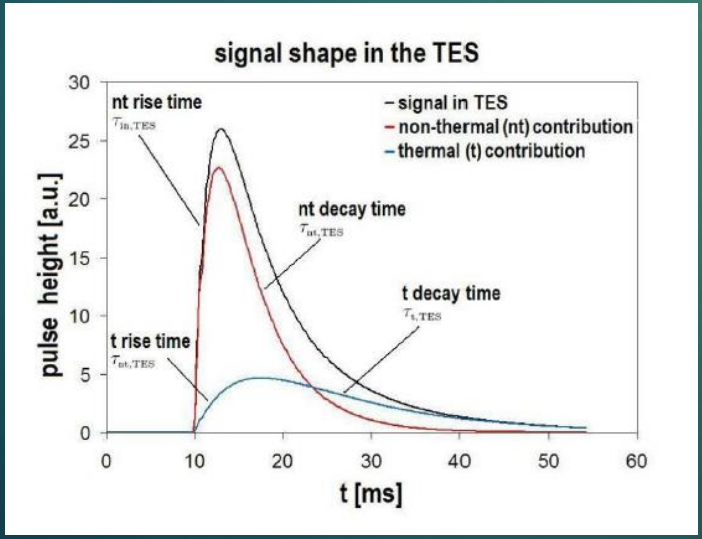
Conclusions

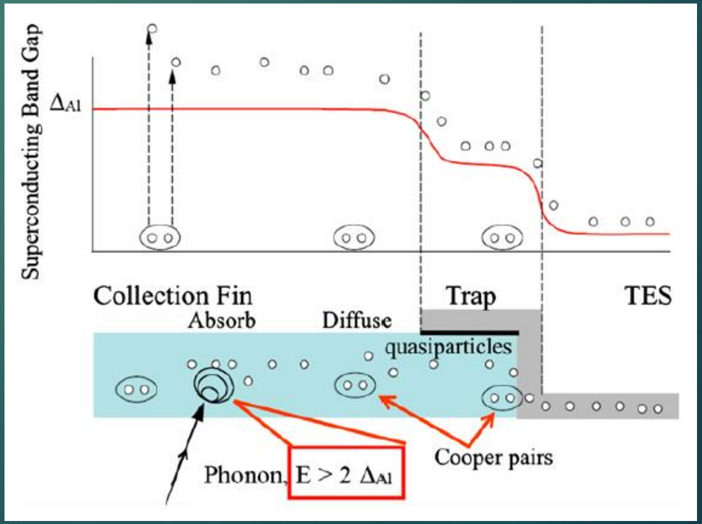
- Our
- A Spiderweb bolometer for CMB has been shown with its fabrication process.

Cryogenic Anti-Coincident concepts



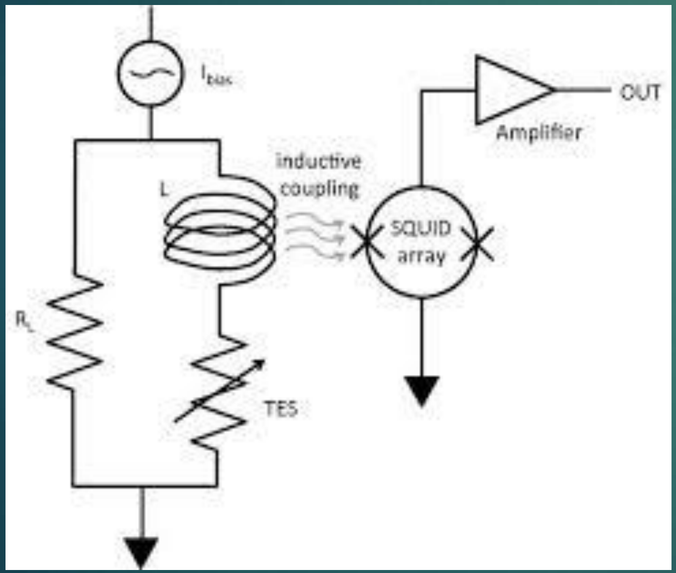
- The absorber is the Silicon substrate
- Superconducting thin film are used as collector to increase the rise time
- Charged particles produce phonons in silicon
- Phonons broke Cooper pairs which are collected on the TES



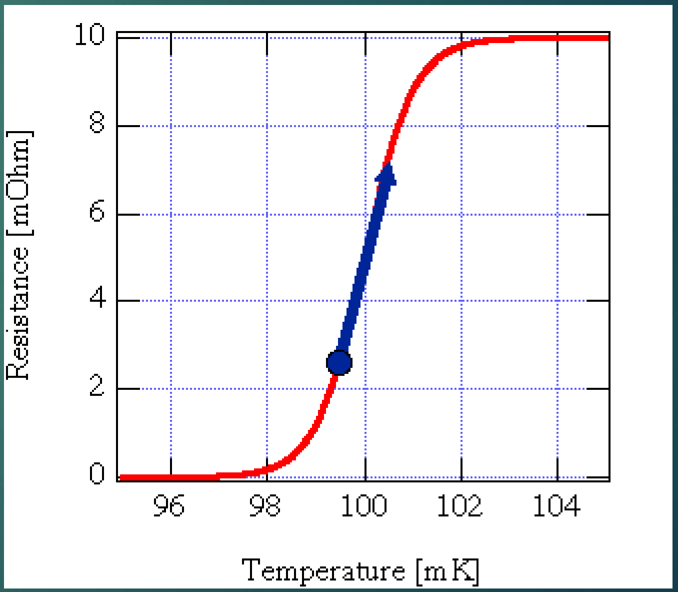


Typical TES readout

TESs are polarized in applying a tension
The signal is read in current using a SQUID as magnetometer

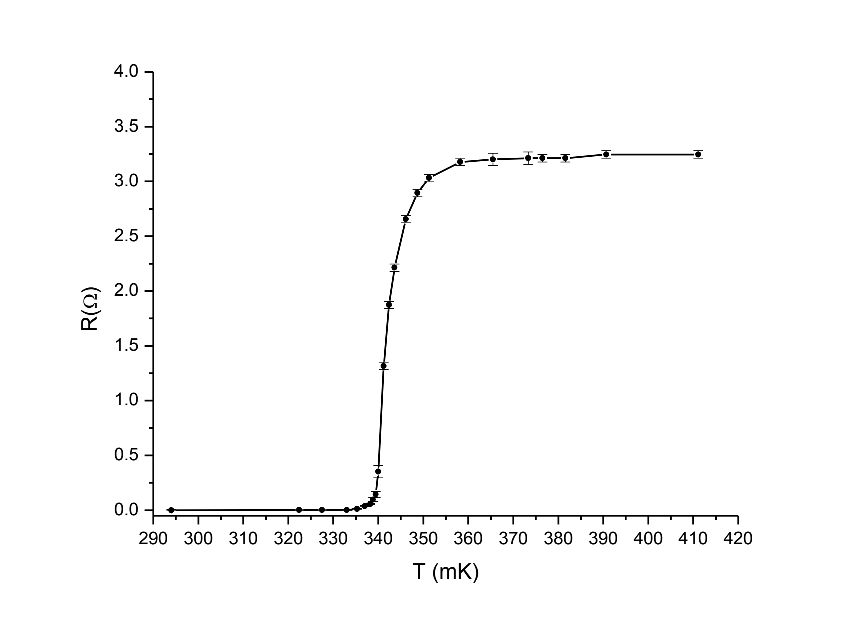


TES positive R(T) slope produce e negative electro-thermal feedback that increase its stability



Preliminary characterization of Spiderweb detector

R(T) transition curve



I-V curves