EURECA:
A CRYOSPECTROMETER PROTOTYPE FOR XEUS

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OUTLINE

- Cryogenic detectors for XEUS

  What?

  Why?

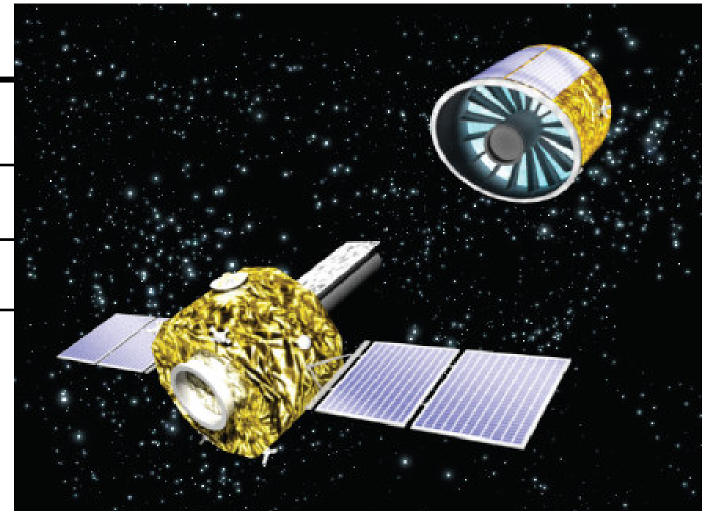
- EURECA
  - The prototype
  - The spanish contribution

XEUS

The X-Ray Evolving Universe Spectroscopy Mission

Key Parameters

Parameter	Requirement (goal)
Spectral range	0.2–15 keV (0.2-40)
Focal length	35 m
Effective area	5 m^2 @ 1 keV 2 m^2 @ 7 keV (1m^2 @ 10 keV, 0.1m^2 @ 40 keV)
Angular resolution	5” (2”) @<15keV
Fields of view	7’ (WFI) 0.75’ (1.7’) (NFI)
Spectral resolution	150 eV @ 6keV (WFI) 6 eV (3) @ 6 keV (NFI) 2 eV (1) @ 0.5 keV (NFI)
Count rate	2 10^6cts/s (HTRS) 3 10^4cts/s
Time resolution	10 μs
Sensitivity	4 10^{-18} erg$cm^{-2}s^{-1}$@0.2-10keV



Near Field Imager:
Unprecedented spectral resolution
Good countrate and sensitivity

XEUS

The X-Ray Evolving Universe Spectroscopy Mission

XEUS - Studying the Hot Universe

- Detection of distant sources → ☆ Large collecting area; ☆ Good angular resolution

- Study the physics of X-ray emitters

  - Resolve the structure of the Fe K_a emission line in AGN

    For nearby X-ray sources: @ 6 keV
    For distant sources: @ soft X-rays

  - Resolve He-like triplets of the most abundant elements (e.g. OVII)
  - Resolve individual emission lines form the galactic background
  - Determine metal abundances on AGNs, SNRs, clusters of galaxies, …
  - Detect resonant absorption lines

→ ☆ High resolution @ <1-2keV
6 keV

X-ray astronomy: the study of the hot Universe

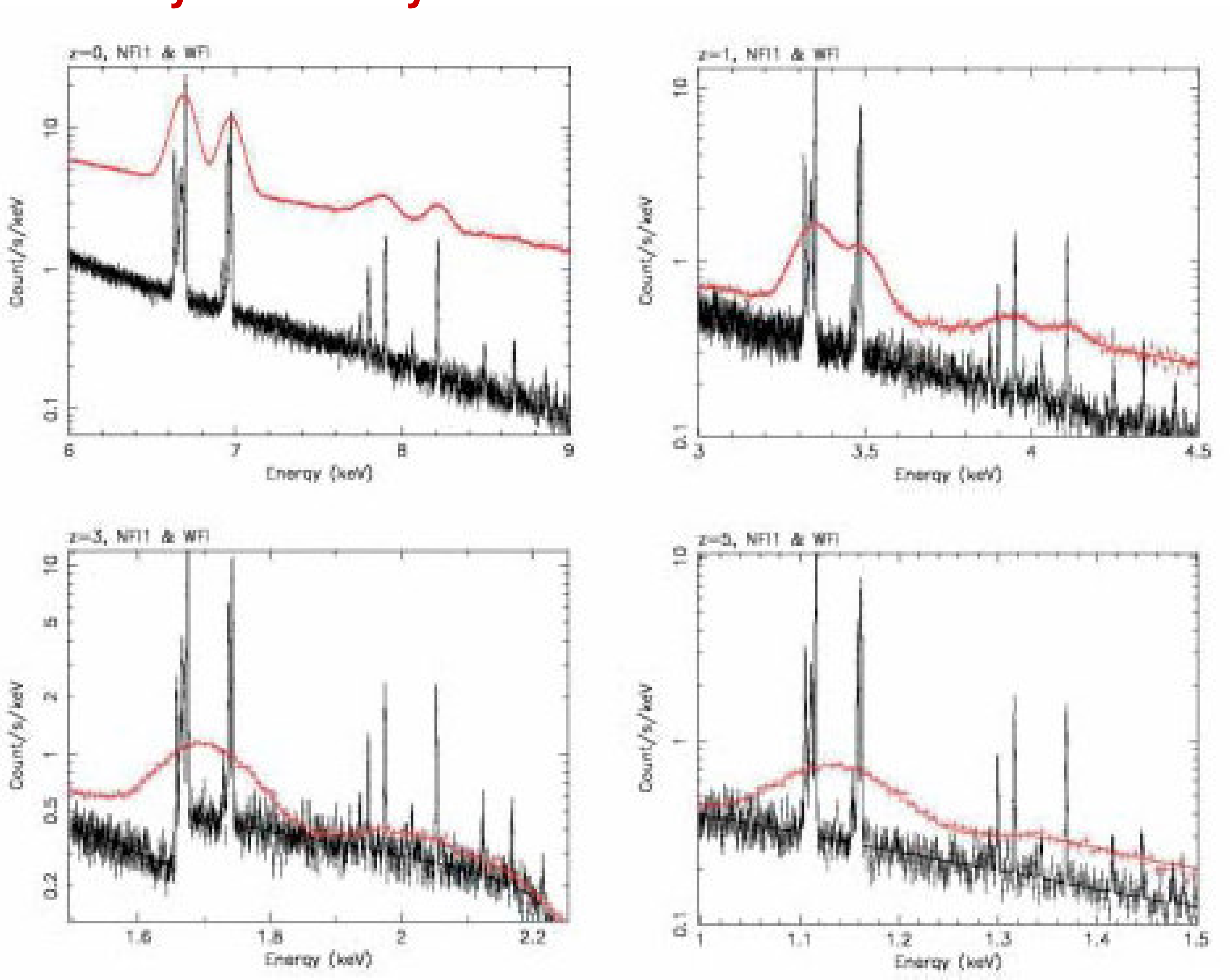


Figure 2.6. The response of NFI1 (black), a tunnel-limited Ta-based STJ, to the iron lines around 6-9 keV (rest frame) from an optically thin plasma with solar abundances having a temperature of ~ 10^8K. Comparison with WFI response (red) for redshifts of 0, 1, 3, 5 and 7.

Demands of increasing:

- Spectral resolution
- Efficiency and sensitivity

Require **CRYOGENIC DETECTORS:**

- Reduction of thermal noise
- Use of superconductors

Superconductor-based detectors:

- High spectral resolution ΔE
- Broadband, high detection efficiency
- High time resolution
- High counting rate

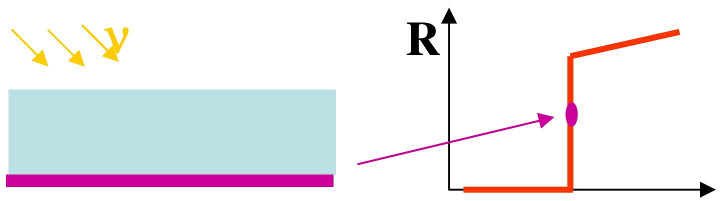
Capability of time resolved
single photon spectroscopic counting

Types of cryogenic detectors

Calorimeters

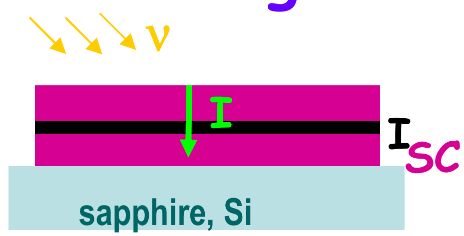
Superconducting

- Si-termistors
- Magnetic microcalorimeters
- Transition Edge Sensors



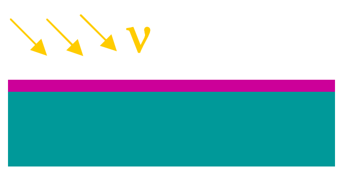
$\Delta T \Rightarrow \Delta R$

- Superconducting Tunnel Junctions



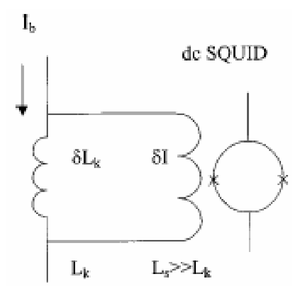
I_{SC} qp excess ➡ net tunnel current

- Kinetic Inductance Detectors



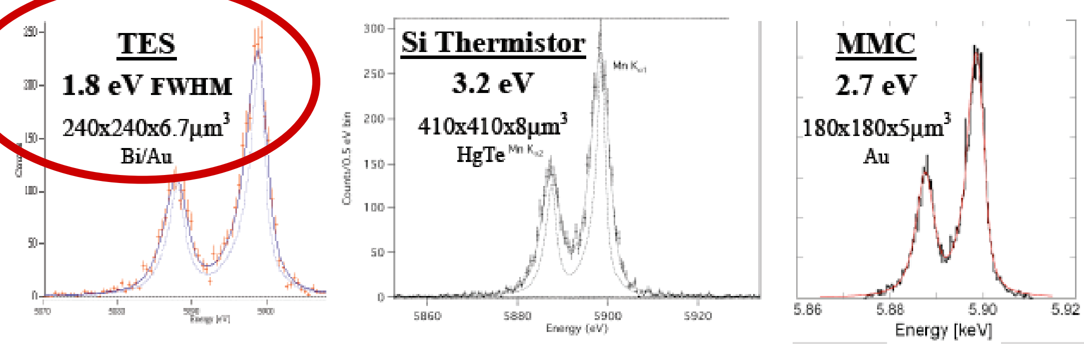
$t<\lambda$

Creation of qp's ➡ ΔL



Demonstrated performances of single X-ray detectors

Detector	Resolution	Time response
CCD	12eV@ 6keV	~ms
DEPFET	50eV@ 6keV (MPI Garching)	1μs, 1ms
Si-thermistor	3.2 eV @ 6keV	
MMC	2.7eV@ 6keV (Fleischmann)	8ms
TES	1.8eV@ 6keV (GSFC-NASA) <2eV@ 2keV (SRON)	100-20μs
STJ	20eV@ 6keV (ESTEC) 2.4eV@ 0.5keV	2μs



LTD12
July 2007

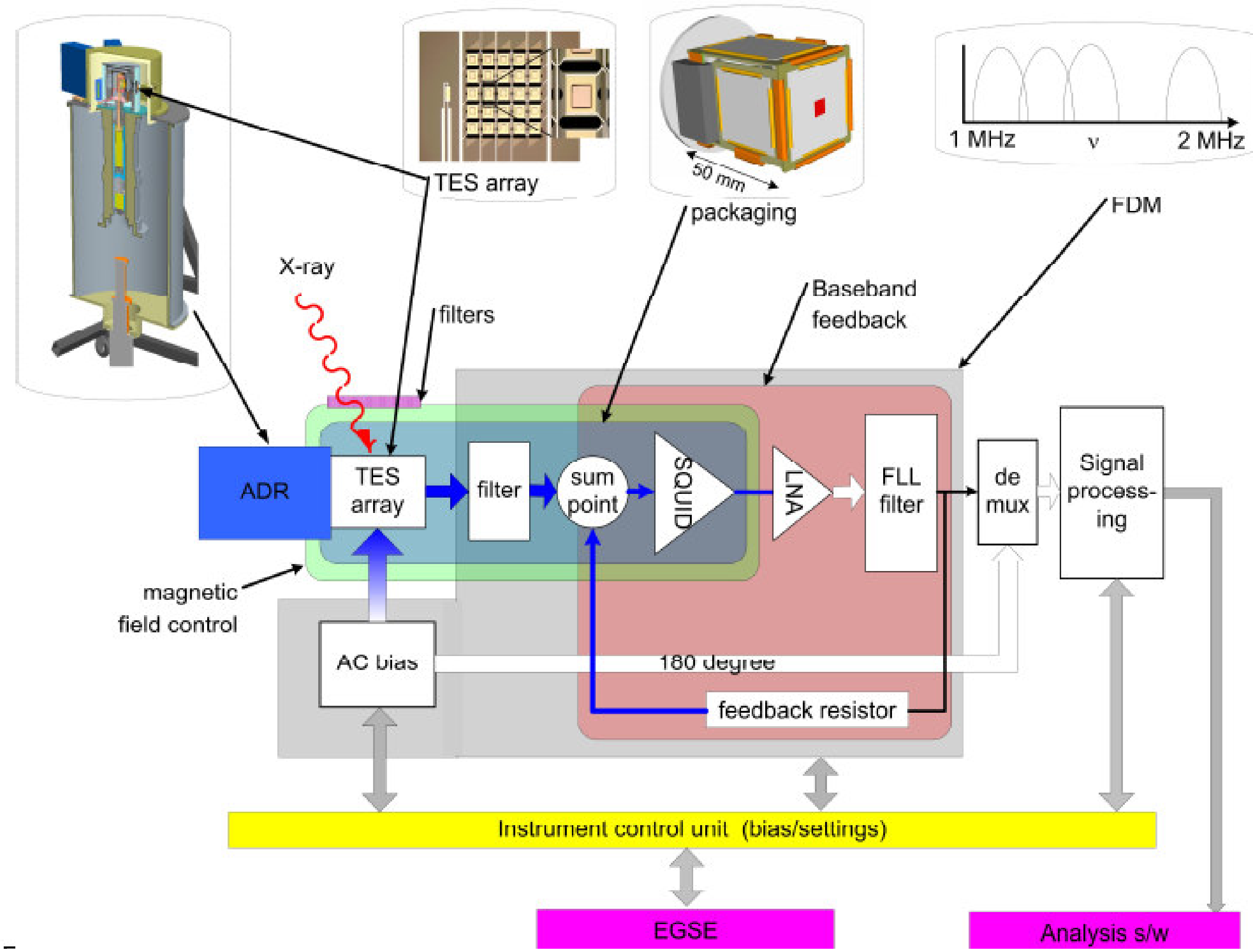
Cryogenic detectors are interesting for

- Particle physics
- Astronomy:
  - X-ray and γ-ray detection (*high resolution and efficiency*)
  - Time-resolved spectrophotometric studies of objects (IR-UV range) *(energy, time and space resolution)*

- Materials analysis (bio and nanotechnology) :
  - X-ray microanalysis (EDS) (*resolution*)
  - X-ray fluorescence analysis (*high counting rate*)
  - Mass spectrometers (*detection of ionization state; high efficiency, independent of mass*)

Cryogenic detectors are the next generation of instrumentation in astronomy and materials science

EURECA: Eurocryospectrometer prototype for XEUS



Proof of technical readiness: Autumn 2009

- **Microcalorimeter array meeting XEUS requirements**
- **Smaller area (5x5 pixels instead of 32x32)**
- **ADR cooler (35mK base temperature; 50mK bath)**

NFI and EURECA specifications

Spatial resolution element (pixel size)	5 (2) arcsec (250 or 500μm) (240μm)
Field of View (array size)	1 arcmin (32x32) (5x5)
Energy range (detection efficiency)	0.1-20keV (>90% for 1-3 keV) 0.1-6keV
Energy resolution	1eV @ 0.1-2 keV
Count rate	>250cts/s/pixel
Effective time constant	100μs
Background rejection	>95% (minimum ionising) particles

Partners of EURECA

- SRON (Space Research Organization of Netherlands). PI: Piet de Korte
- ESTEC (ESA)
- Mullard Space Science Laboratory; Univ. Leicester (UK)
- VTT; U.Helsinki (Finland)
- Kirchhoff Institut für Physik; Univ. Heidelberg (Germany)
- INAF (Rome); INFN (Genova); Alenia Spazio (Milano)
- JAXA; Metropolitan Univ.; Seiko II (Japan)
- **ICMAB, IMM-CNM, ICMA, INA, IFCA (Spain)**
- Paul Scherrer Institute, ISDC (Switzerland)

The Spanish contribution to EURECA:

- Development of new TES sensors based on Mo/Au
  - Fabrication
  - Cryogenic characterization
- Triming of LC filters for multiplexed readout
- Quick-look and data analysis software
  - Development
  - Coordination

⇨ **Next talk**

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F.Carrera, J.Bussons, M.T.Ceballos, J.R.Rodón

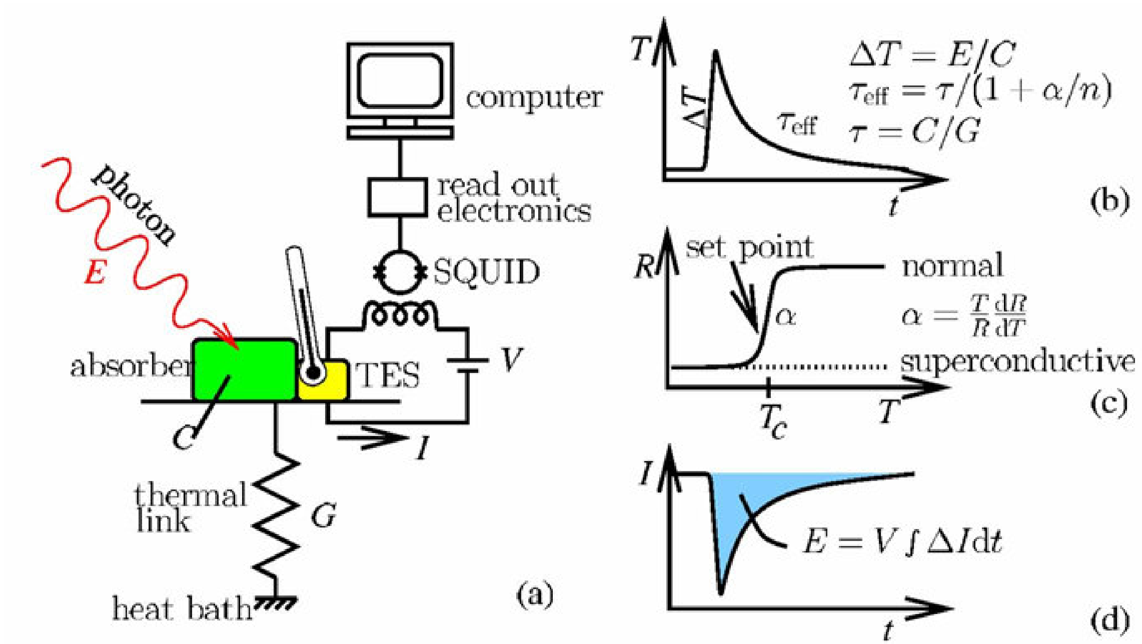
ICMAB

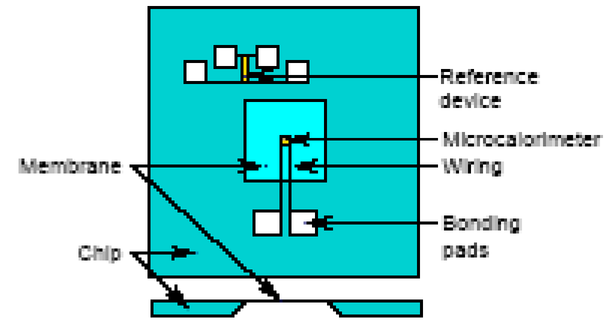
CENTRO NACIONAL DE MICROELECTRÓNICA IMM

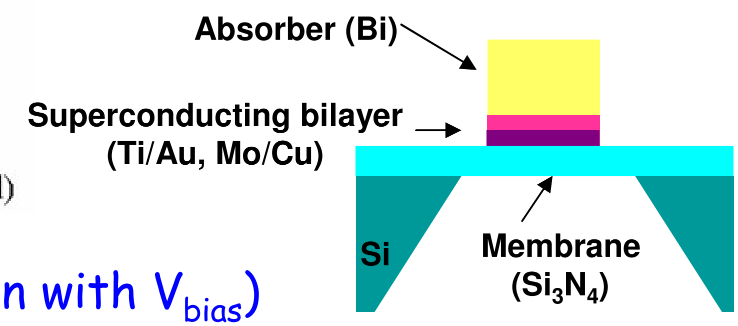
icma INSTITUTO DE CIENCIA DE MATERIALES DE ARAGÓN

IFCA Instituto de Física de Cantabria

SUPERCONDUCTING MICROCALORIMETERS FOR X-RAY DETECTION



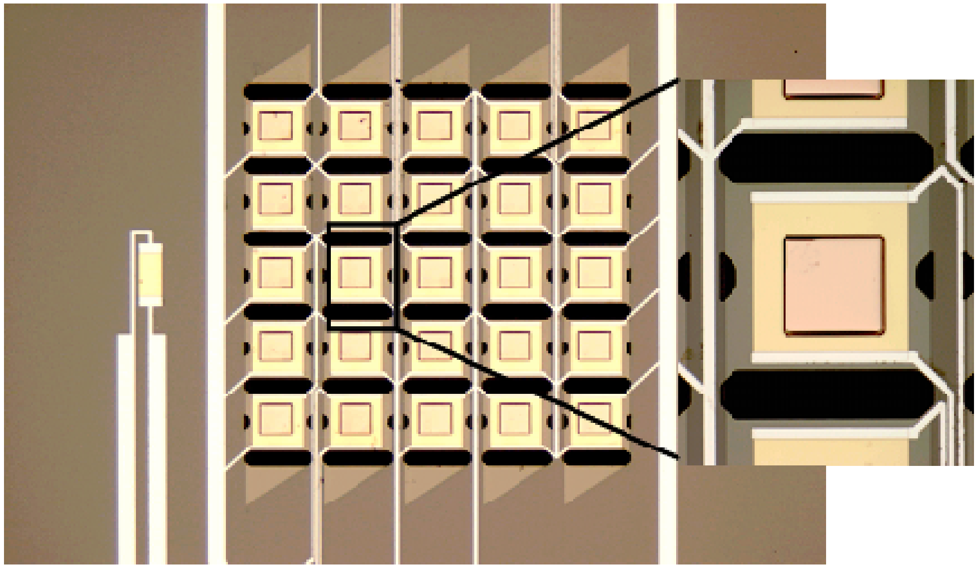




- ETF mode (excited at the middle of transition with V_{bias})
- T_{op}<100mK
- Very sensitive to H, I, geometry, C
- Typical dimensions: 240x240mm^2

$$\Delta E_{FWHM}=2.36\,[0.5n]^{1/4}\sqrt{4kT^2C/\alpha} \qquad \tau \approx C/\alpha\ T/P$$

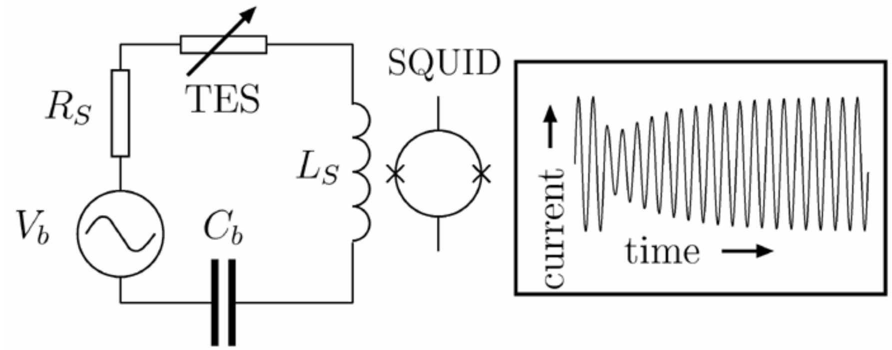
LARGE AREA FORMAT: ARRAYS

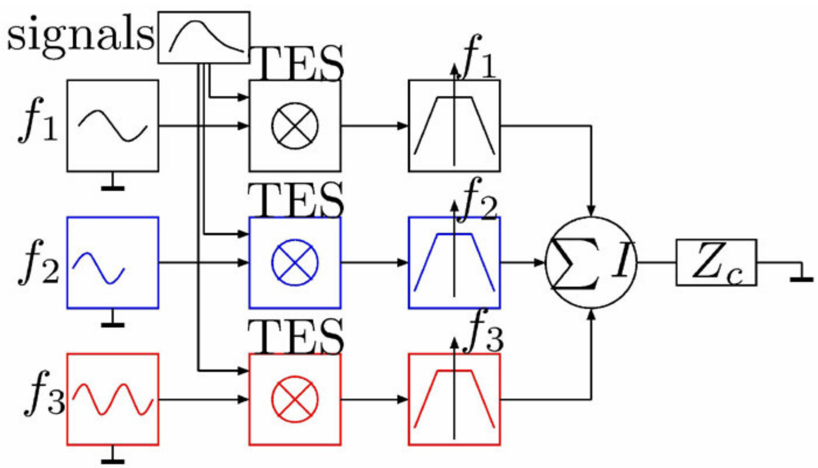


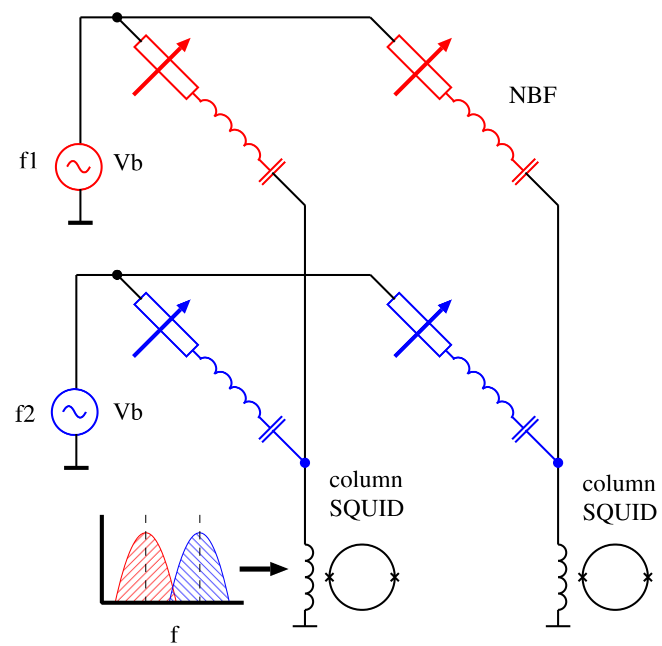
☆High filling factor
☆Good resolution in position

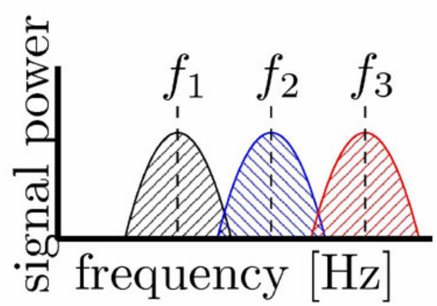
Readout of TES arrays : frequency domain multiplexing

AC readout:





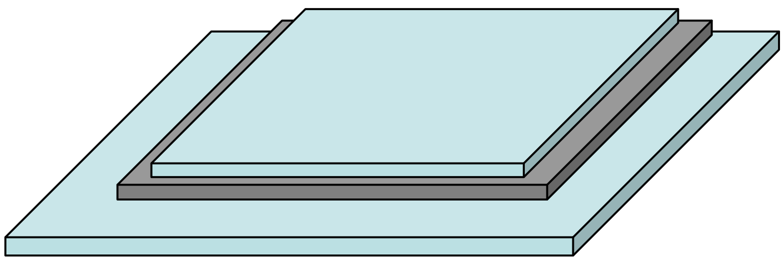


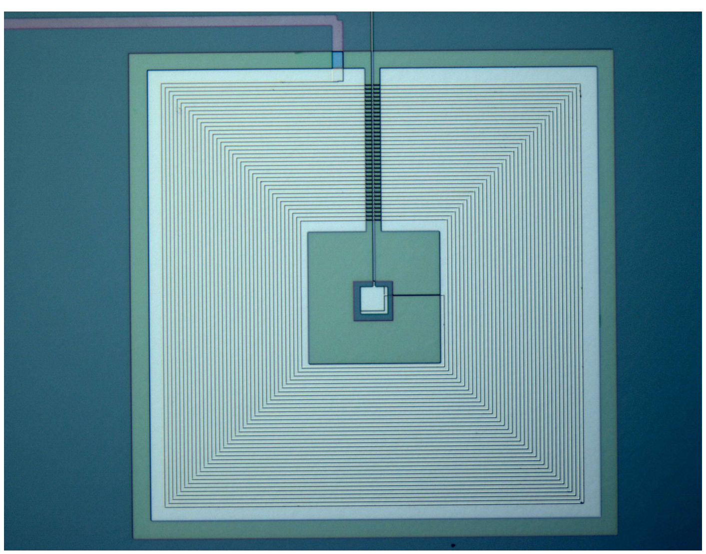


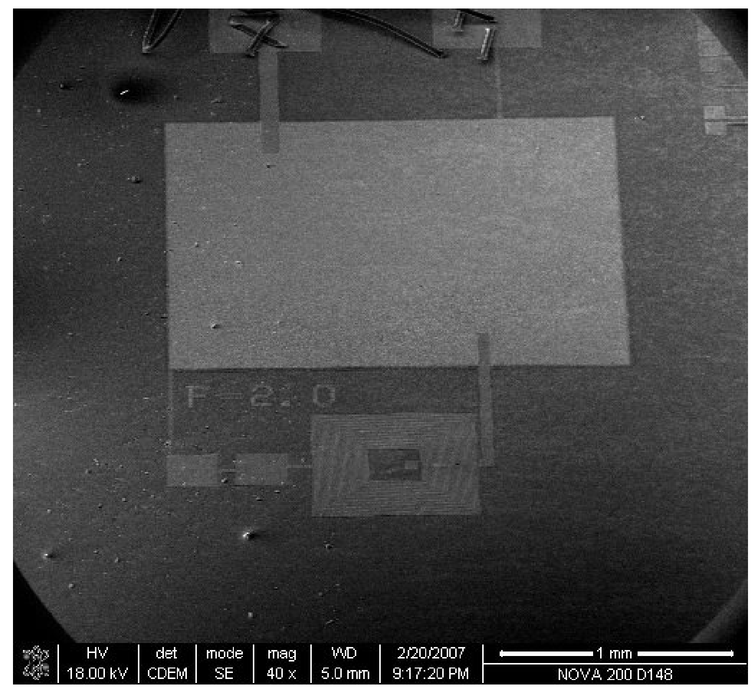
LC noise blocking filters required

Triming of the LC filters

- Coil inductance L=380nH
- Capacitance range 0.67-67nF at 10-1 MHz
- Q>680 f (MHz)
- C density >1.7nF/mm^2
- High tuning accuracy: 800Hz in 1 to 10 MHz
- The resonance frequency of similar filters has to be matched to **0.01**%



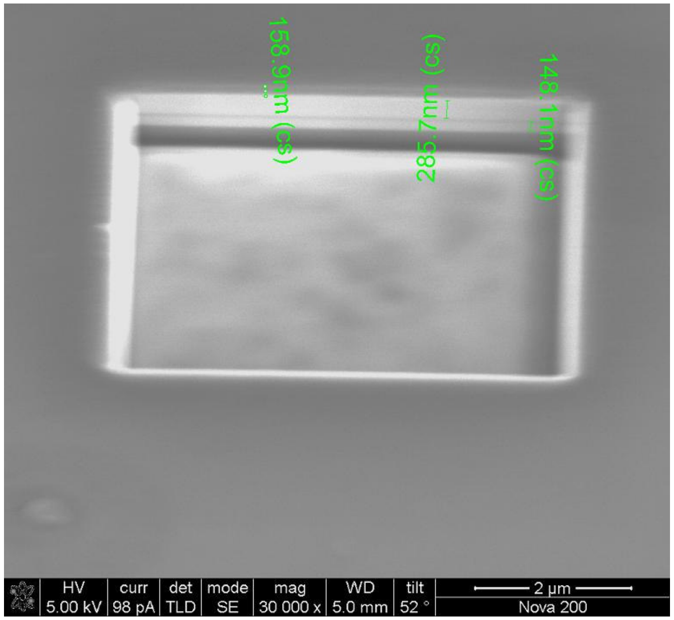




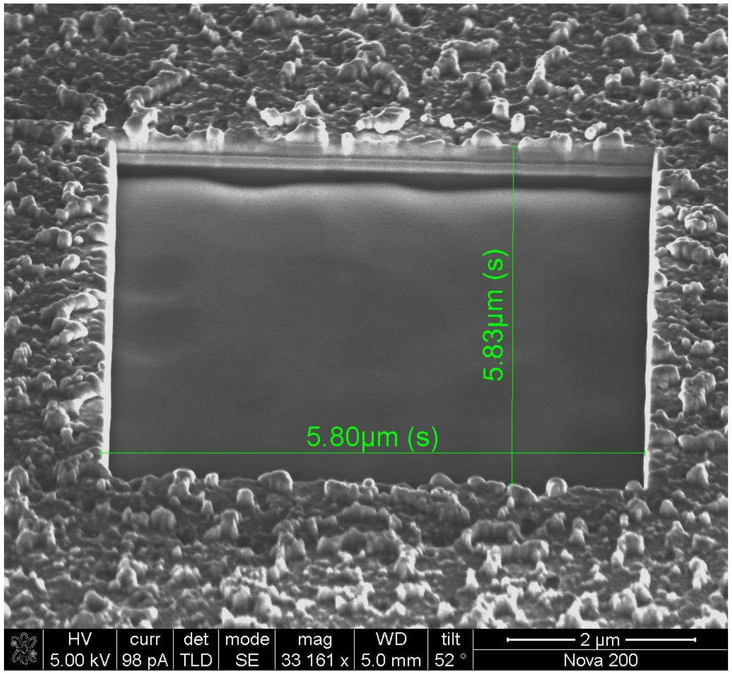
Fabrication is only 1% accurate, so a triming process is required

Triming of the LC filters using Focused Ion Beam

FEI Nanolab 200 Dual beam
(SEM + FIB) in operation at INA



Very small areas of capacitor can be removed (<1mm^2)



➡ Triming with a 0.000001% accuracy

SC/M bilayers for TES

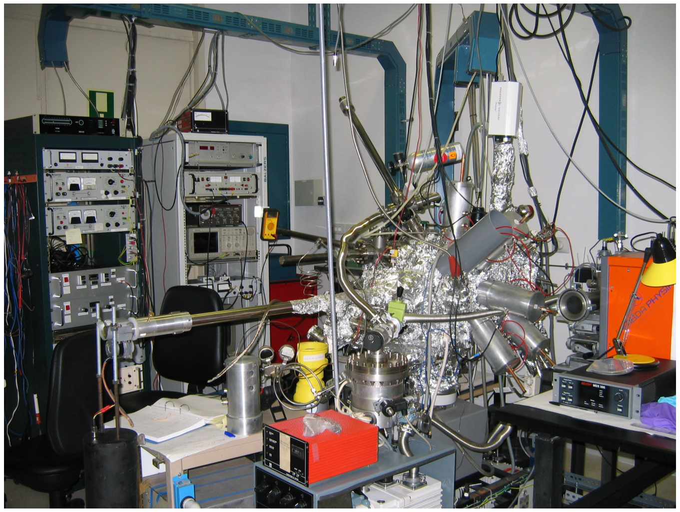
- ✓ Excellent control of T_c by the superconducting proximity effect
- ✓ M= noble metal: controls R and C; can be used as absorber

Best TES fabricated :

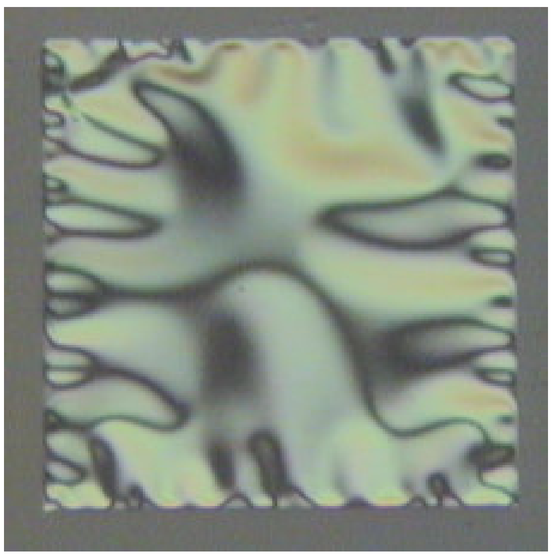
	T_c	R_n	C	ΔE
Ti/Au 18nm/50nm (SRON 2007)	100mK	300mΩ	0.5pJ/K	2.5eV @ 6keV (<2eV @ 2keV)
Mo/Au 50nm/270nm (GSFC 2007)	100mK	9.8mΩ	1.6pJ/K	2.1-1.8eV @ 6keV
Mo/Cu (NIST, 2007)	100mK			2.4 eV @ 6keV

- Ti/Au: eventual stability problems
- Mo/Au(Cu): Thicker, more stable
  Difficult to fabricate

Fabrication of Mo/Au bilayers by sputtering



Experimental setup at the IMM (Madrid)



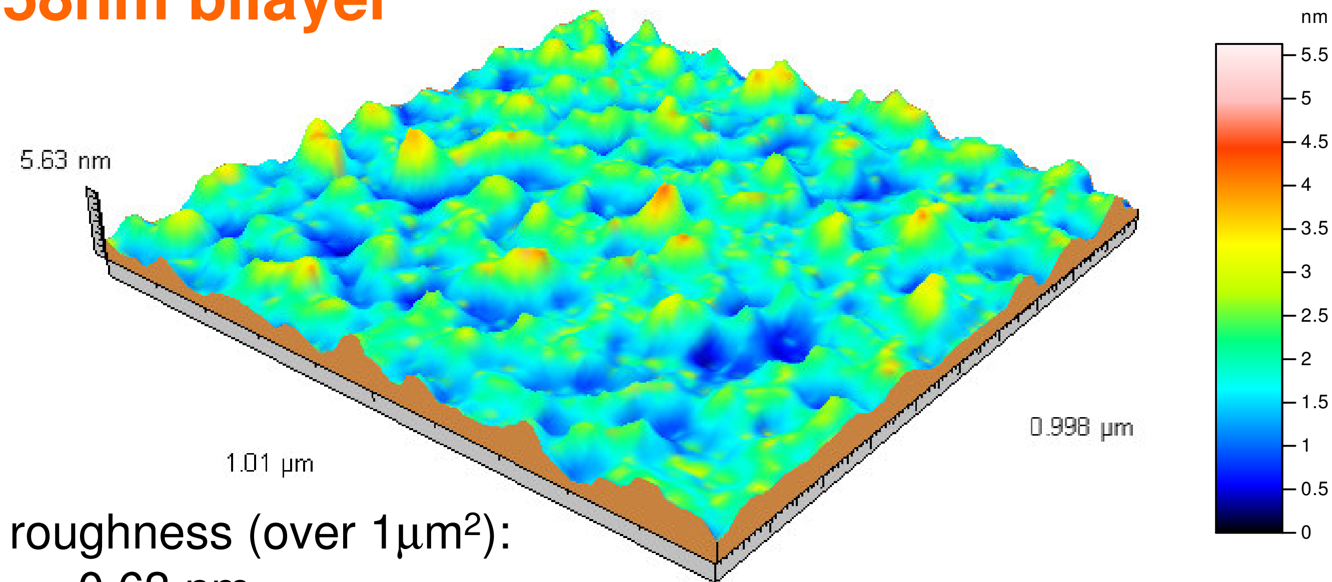
Substrate:

$Si_3N_4/SiO_2/Si$
(bulk o membranes)

Growth conditions:

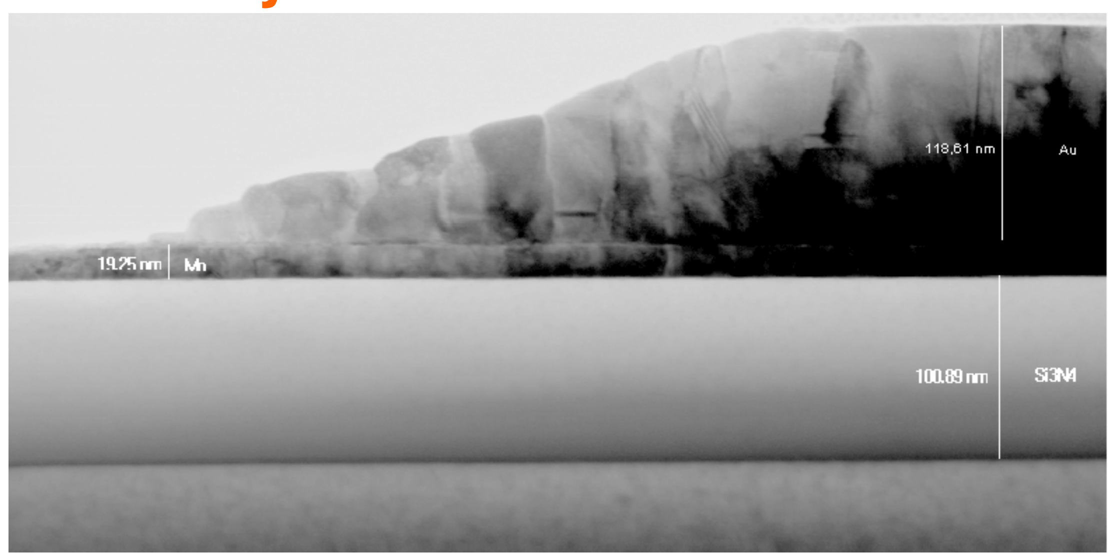
Mo	Au
RF magnetron	DC triode
W=210 W	Vc=2kV
$6x10^{-3}$ mbar	$8x10^{-3}$ mbar
RT	RT
7 **(Å/s)**	1,4 **(Å/s)**

28nm/58nm bilayer



Average roughness (over 1µm²):
0.63 nm

25nm/114nm bilayer



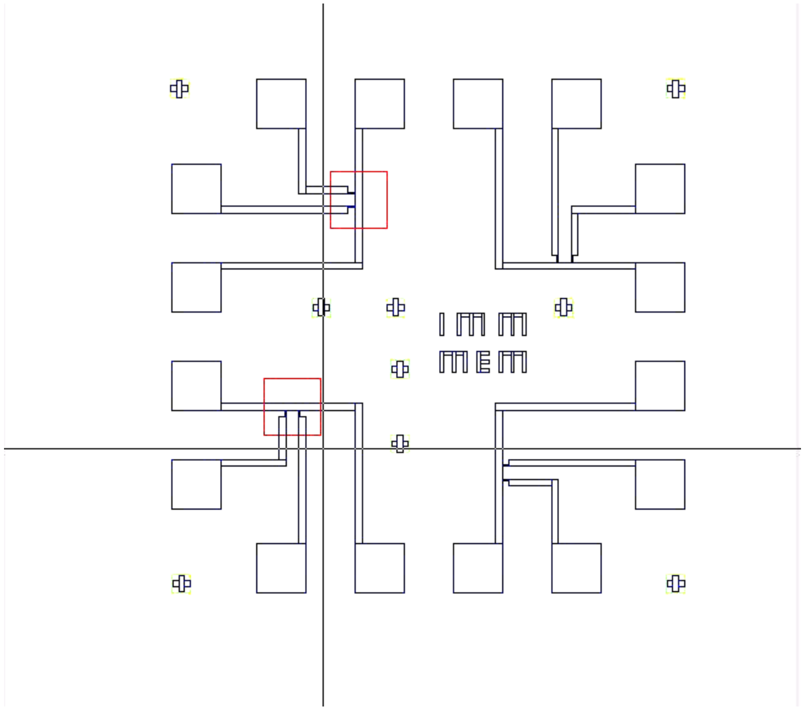
- **Cryogenic characterization**

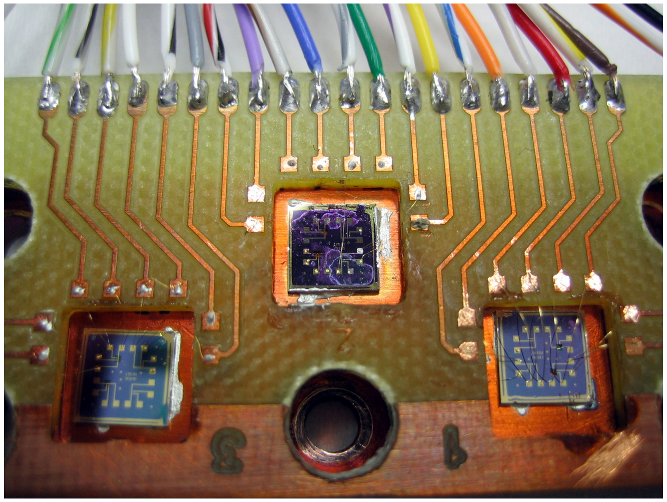
Dilution refrigerator:

Kelvinox MX40 (Oxford Instruments)

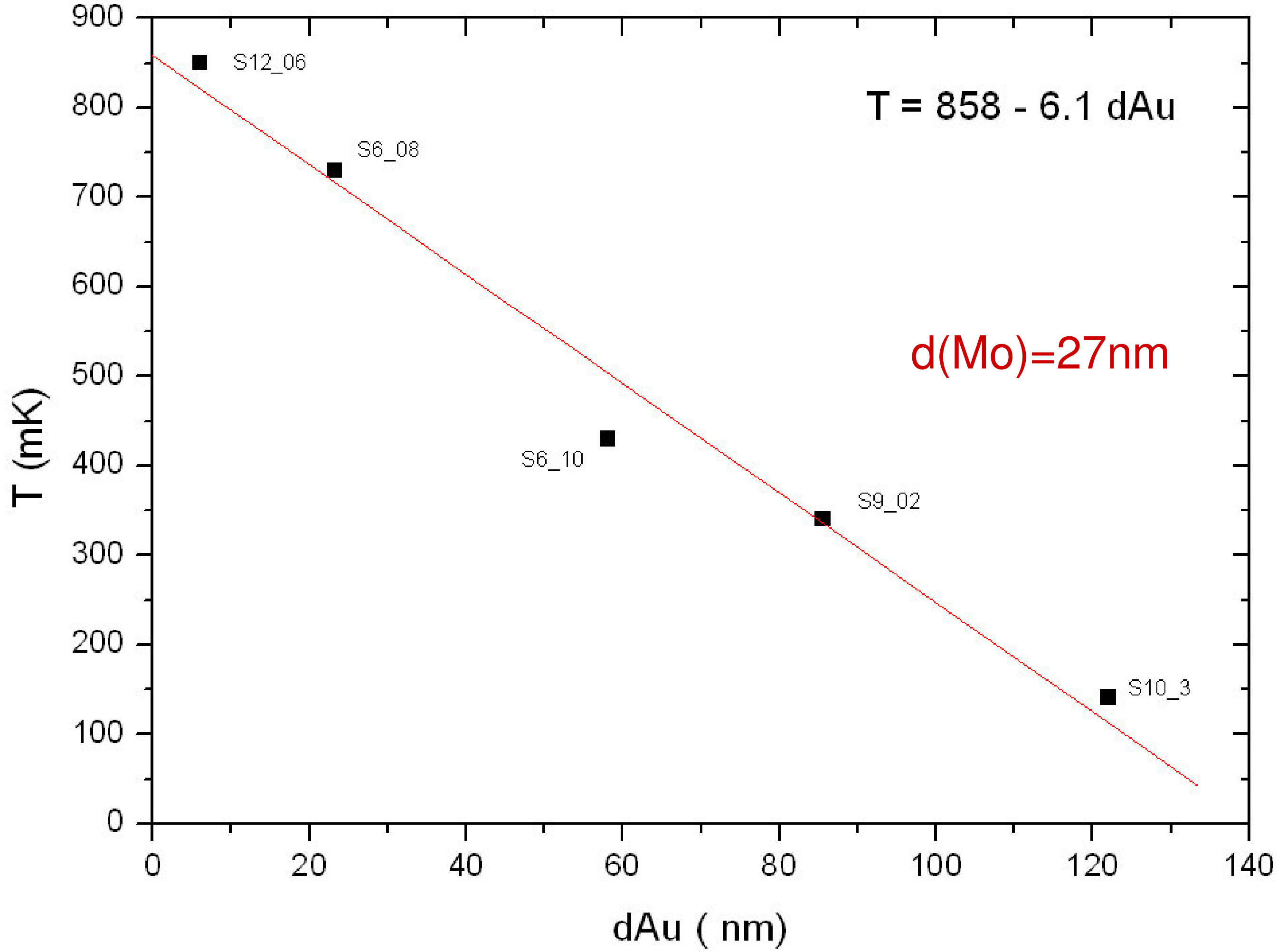
- **Sample in vacuum**
- **Base temperature 27 mK**
- **Refrigeration power 80 mW at 100mK**
- **Wiring 24 +24**
- **dT/dt = 10^{-2} mK/s**

- **Field screening**
- **Low H superconducting coil**





Superconducting transition of Mo/Au bilayers



Linear dependence T_c vs. d_{Au}

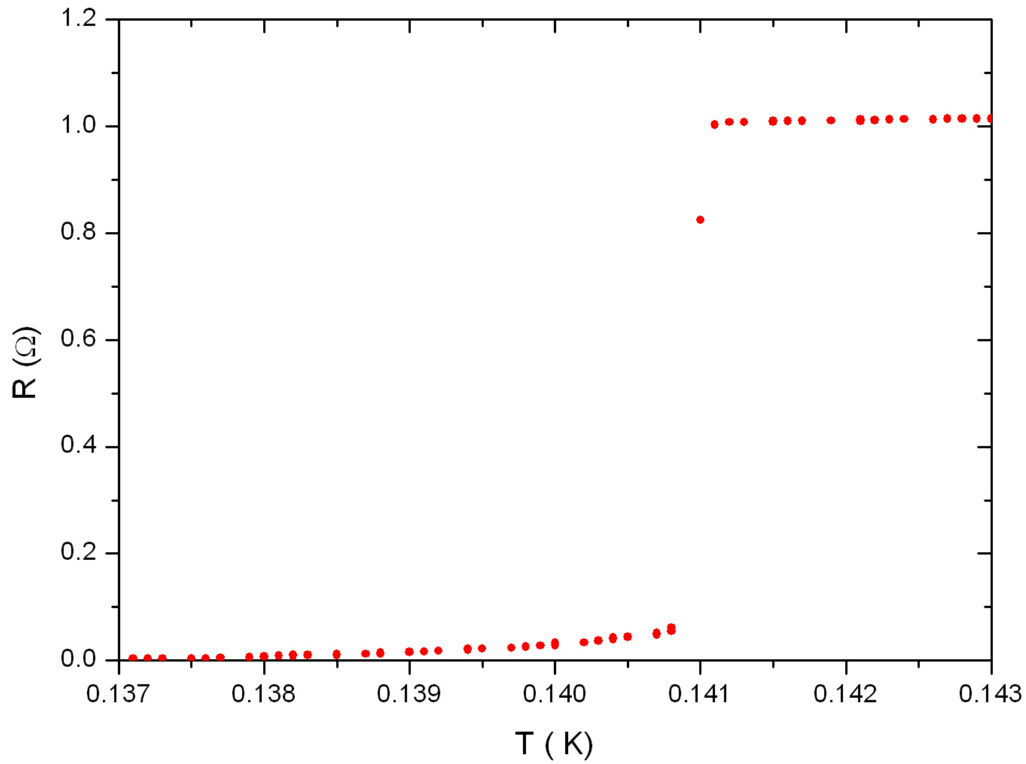
Superconducting transition of Mo/Au bilayers

Mo/Au bilayer (27nm/122nm) on a membrane

$R_{300\,K}$ = 1.4 Ohm
$R_{residual}$ = 1.04 Ohm
RRR = 1.35

ρ ~ 1.5 Ohm m

T_C = 141 mK
ΔT = 0.3 mK



At present

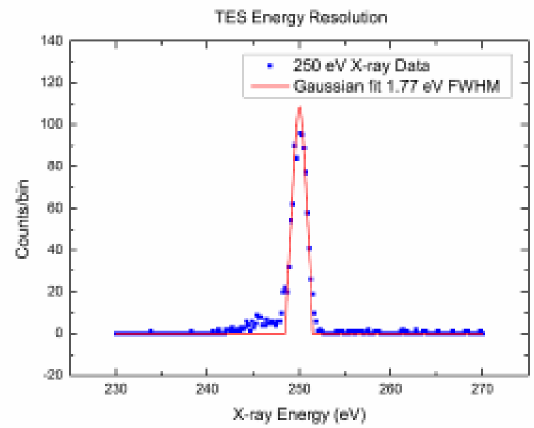
- Microstructure and composition characterization
  - ↳ Correlation fabrication-microestructure-proximity effect
- Improvement of resistance (Cu, Au)

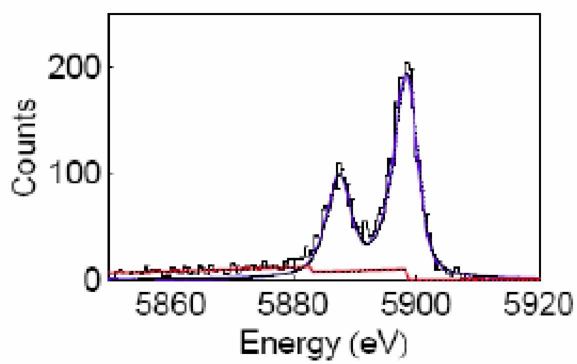
↳ Optimization of bilayers for TES
Advanced characterization: Ic(B), α(B)

↳ TES design, including absorber

EURECA recent progress

- First measurements of single-pixel non-optimized cryo cooled device @ BESY, delivers energy resolution close to goal.
- Commercial LC filters
- EGSE (electronics) designed and on track
- Software designed and very advanced
- ADR being developed



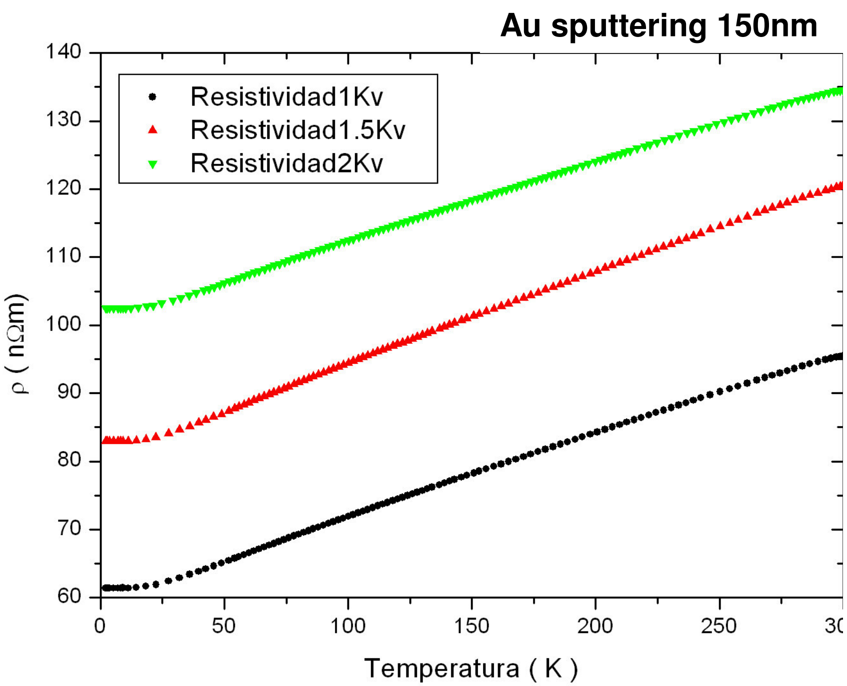


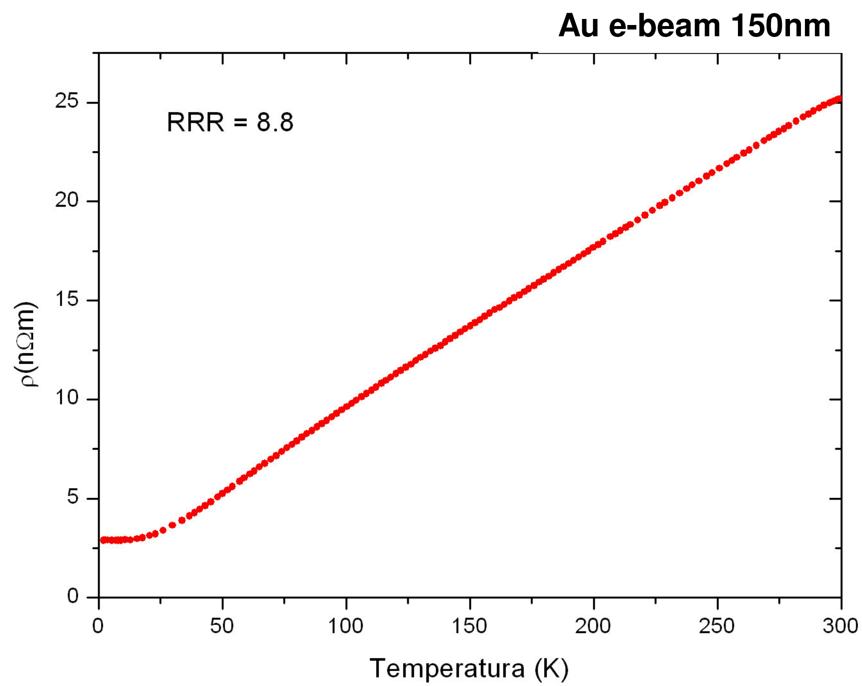
Conclusions

- Cryogenic radiation detectors are the new generation of instrumentation for:
  - Space applications
  - Materials analysis (EDS, mass spectrometers)

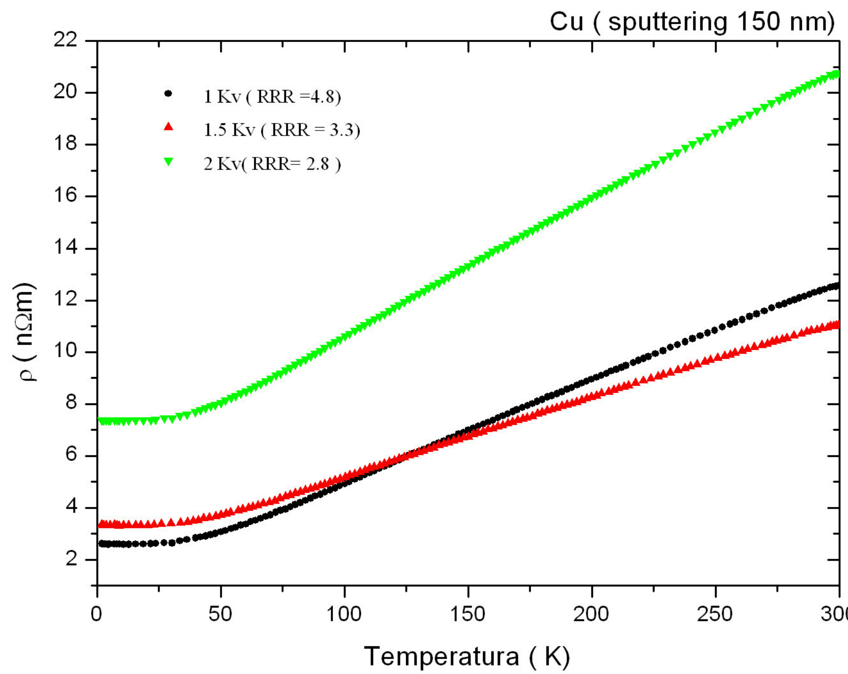
- EUREKA is an European consortium to prove readiness of a cryogenic spectrometer for the NFI of XEUS

- Spanish team involved in EURECA with the tasks :
  - Fabrication and cryogenic test of new TES sensors
  - Development of software of analysis
  - Triming of LC filters for readout electronics





Sputtered Cu and e-beam evaporated Au display suitable R_{sq}



Cryogenic detectors for Materials Analysis

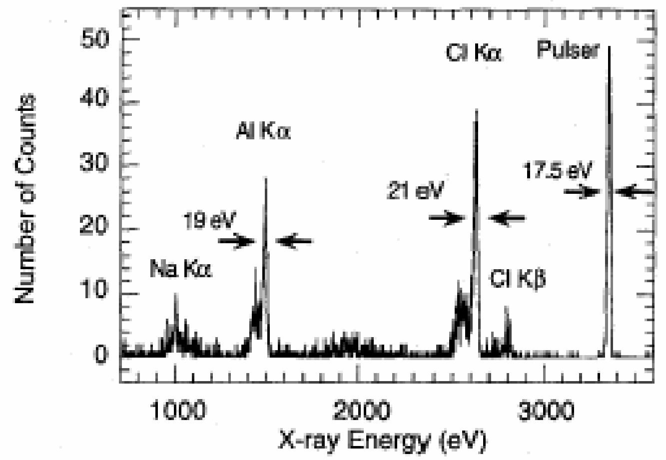


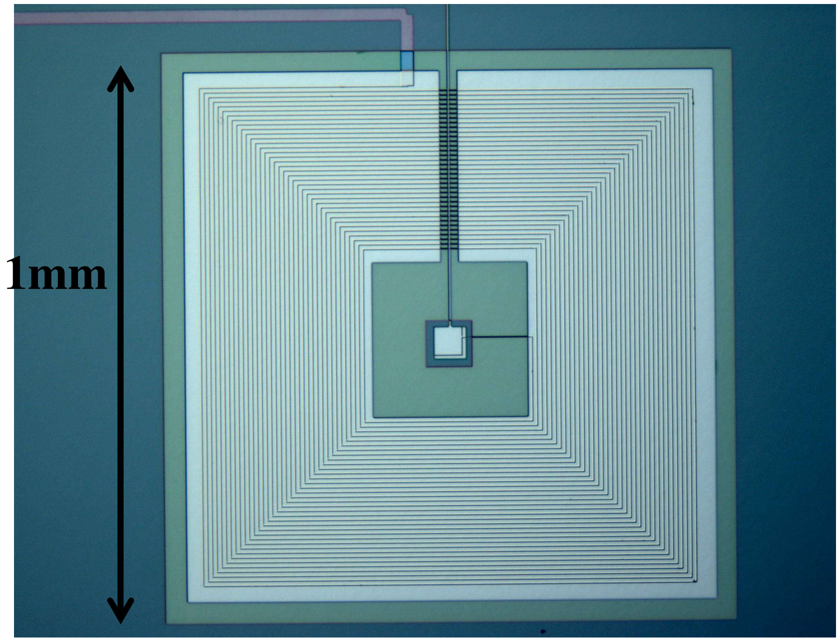
Fig. 5. X-ray spectrum measured using absorption events occurring in the top niobium film. The measured resolution is more than 5 times better than that obtainable with semiconductor based ionization detectors. The smaller, wider line just below the main peaks are due to absorption events in the overhanging niobium region near the edge of the junction.

X-ray fluorescence spectrometers for contaminant analytics	• Microelectronics • Steel industry • Automotion • Nanotechnology
Mass spectroscopy for large molecules	• Pharmacy: (quality, drug discovery) • Medical diagnosis • Polymer chemistry (quality control) • Forensics • Agrobio industry • Biology
FIR Spectrometers	• Environment and polution control • IR Molecular Spectroscopy • Radioastronomy

LC FILTERS

- Coil inductance L=380nH
- Capacitance range 0.67-67nF at 10-1 MHz
- Q>680 f (MHz)
- C density >1.7nF/mm^2
- Frequency acuracy 0.5% and 0.05% for 1 and 10 MHz

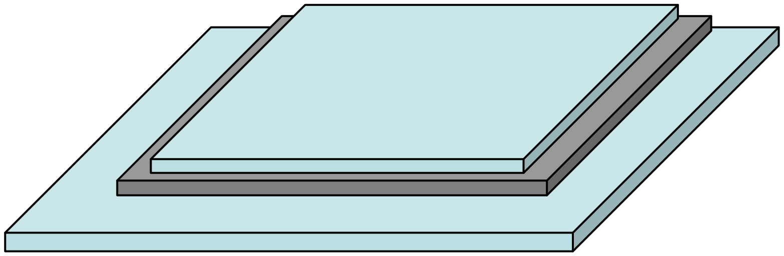
- Inductance



36 turn, 7 micron pitch, spiral on washer superconducting coil (Nb) with a nominal induction of 500 nH.

$$L=N^2L_w$$

- Capacitance

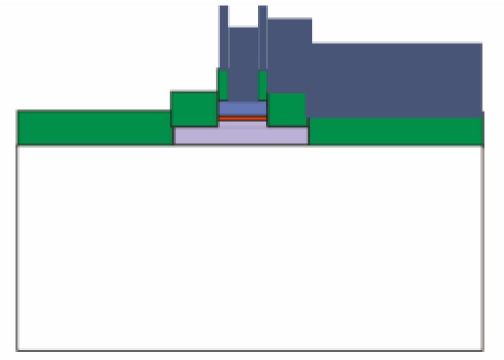


Si_3N_4 dielectric

2. LC filters

Fabrication and test at 4.2K

Improvement of capacitors:



Key issues:
High Q (680 f)
High C density (>1.7nF/mm²)
of the capacitor

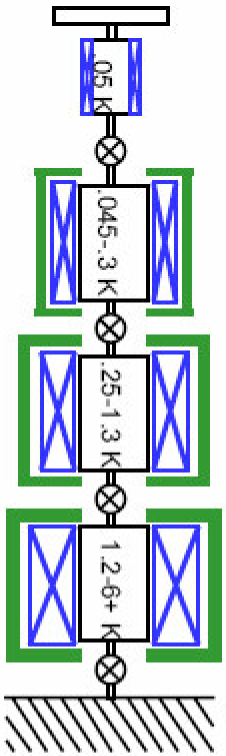
- Dielectric material effects (SiO, SiN, AlO..),
- Dielectric thickness dependence (50nm,… 5nm)
- Metal/dielectric interface quality (in-situ process possible?)
- Substrates (Oxidized Si, glass, quartz..)

Dielectric	Q_{exp}
Ta_2O_5	70
Nb_2O_5	333
Si_3N_4	630-2800
Al_2O_3	

Dielectric	ε_r	thickness (nm)	C (nF/mm^2)
SiN	7,8	50	1,38
Al2O3	9,8	50	1,73
SiO2	3,9	50	0,69

A Compact, Continuous Adiabatic Demagnetization Refrigerator With High Heat Sink Temperature

Peter Shirron, Edgar Canavan, Michael DiPirro, Michael Jackson, and James Tuttle
Cryogenics and Fluids Branch/552
NASA/Goddard Space Flight Center
Greenbelt, MD 20771



Continuous ADR:

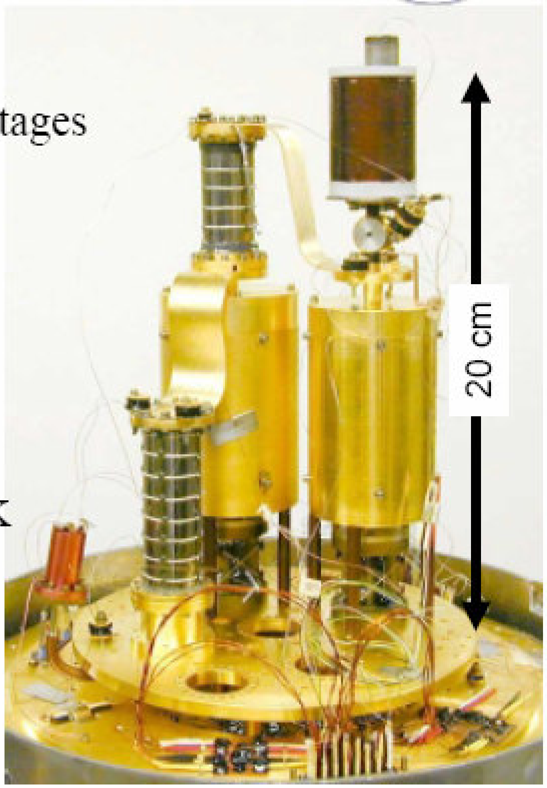
- Lowest temperature stage isothermal
- Heat cascaded to higher temperature stages

Performance of 4-Stage CADR

- Continuous cooling at 35-100 mK
- Heat rejection at 4.2 K
- Cooling power :
  1.5 μW@ 35 mK → 21μW @ 100 mK
- High thermodynamic efficiency (>45%)
- 8 μK rms temperature stability at 100 mK
- Total mass ~ 8 kg

New developments:

- Compact 4th stage operates from > 5K
- All passive gas gap heat switches - eliminates major inefficiency



Interés de los detectores STJ

I. Análisis de Materiales

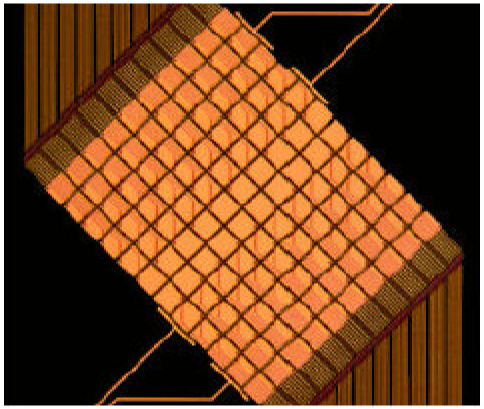
- Espectrometría de masas *(resolución independiente de la masa)*
- Microanálisis de RX (EDS) *a nanoescalas*
- Fluorescencia de RX (*alta velocidad de contado*)

II. Astronomía

- Estudios espectrofotométricos (IR-UV) de objetos con resolución temporal

Estudio de fuentes que varían rápidamente: púlsares, estrellas binarias, AGN...

➡ **SCAM en La Palma**



- RX blandos con alta resolución y eficiencia

➡ **XEUS** ***Estudio del universo caliente, joven***

The need for high-resolution X-ray spectroscopy

- Resolving individual emission lines from the Galactic background
- Metal abundances in AGN, SNRs, Clusters of galaxies, etc.
- Plasma diagnostics: resolve the He-like triplet of OVII
- Resolve the structure of the Fe Kα emission line in AGN
- Detect resonant absorption lines