EURECA: the X-ray Universe in high spectral resolution

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Abstract EURECA is a multinational project (European and Japanese) with the goal of building a prototype for a X-ray spectrometer based on Transition Edge Sensors (TES), with a view to new space missions, in particular XEUS/IXO. In this presentation we will describe the technological and scientific objectives of this project, and the Spanish participation in it, including development of software for scientific and calibration data analysis, development and building of superconducting bilayers, and characterization of LC filters for TES.

1 Introduction: the need for high resolution X-ray spectroscopy

X-ray Astronomy provides a privileged window to the most energetic Universe. With the advent of the last generation of large X-ray observatories with large collecting area and gratings (*XMM-Newton* and *Chandra*) the physical study of many astronomical objects via spectroscopy has become possible.

The next generation of X-ray observatories (XEUS/IXO [1]) will need high spectral resolution to continue further these advances in several areas, such us resolve individual emission lines over the Galactic background, to study chemical abundances in AGN, SNR, galaxy clusters and many other sources, to perform plasma diagnostics (such as resolving the He-like triplet of OVII), to resolve the structure of the Fe Kα line in AGN, or to detect resonant absorption lines.

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2 EURECA

The EURopean-JapanEse Calorimeter Array (EURECA [2]) is a transnational project to demonstrate technical readiness to build a X-ray spectrometer with imaging capacity based on TES. The concrete goal is to build and test a prototype by Autumn 2009. The PI of the project is Piet de Krote from SRON (Netherlands).

There are collaborators from many countries: Spain (ICMAB, ICMA, IMM, INA, IFCA), Germany (U. Heidelberg), UK (MSSL, U. Leicester), Netherlands (SRON and ESTEC -ESA-), Finland (VTT, U. Helsinki), Japan (ISAS/JAXA) and Switzerland (PSI, ISDC).

The team for the analysis and visualization of the data is led by IFCA (the coordinator is Francisco J. Carrera), with the collaboration of ISDC and SRON. The contact with the instrument team at SRON is via Jan van der Kuur.

The long term goal for EURECA was to demonstrate that Europe and Japan could build a 32×32 array of TES calorimeters with a resolution of about 1 eV, with a view to form an international consortium to bid for the *High Resolution Instrument* on board the ESA/JAXA mission *XEUS*. The recent merging of *XEUS* and *Constellation-X* from NASA into a single collaborative mission provisionally named *International X-ray Observatory* (*IXO*) is a challenge to the project, which is nevertheless progressing steadily.

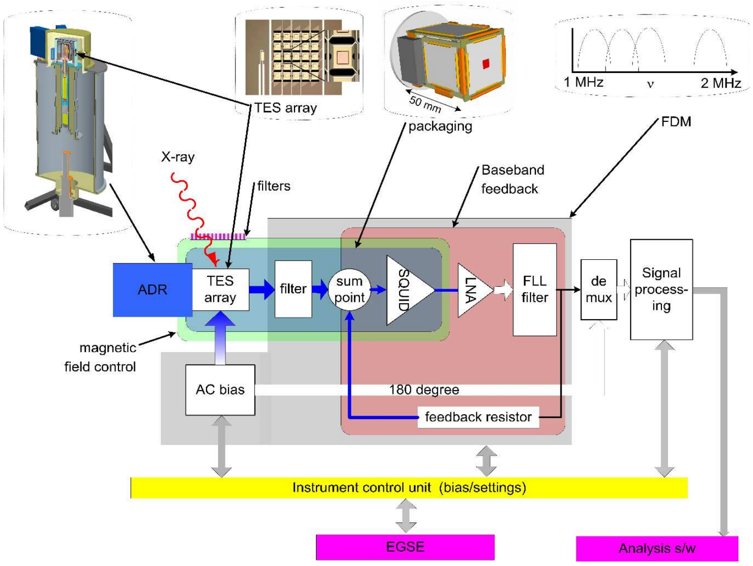

Fig. 1 Schematic diagram of the different parts of the EURECA instrument, including the cooler (ADR), the TES sensor, the reading electronics and the signal processing

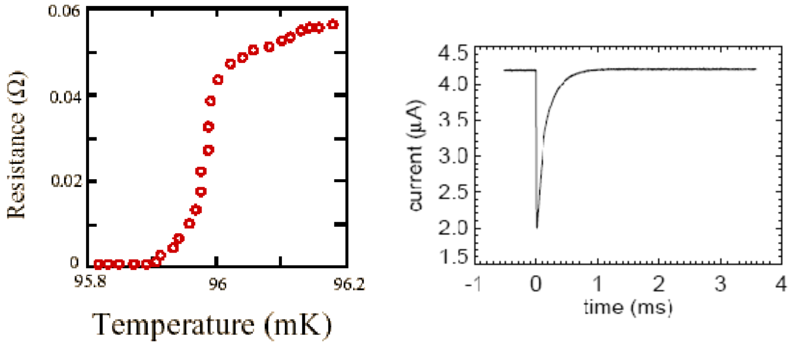

Fig. 2 Left: Resistance versus temperature for a normal to superconductor transition in a TES sensor. Right: measured current versus time in a TES sensor during the detection of an incoming photon.

2.1 Transition Edge Sensors

The physical basis for a TES is a thin layer of superconducting material cooled to very close of its critical temperature T_c by a thermal bath. This material which is excited by a voltage V_{in}. Thermally coupled to it there is an absorber material. When incoming radiation (X-rays in the case of EURECA) hits the absorber, it increases the temperature of the superconductor, altering dramatically the resistance R, and hence the output current I_{out}. As the thermal bath restores the working temperature of the TES, the current returns to its nominal value. This change of current is detected and analysed to reconstruct the energy of the incoming radiation. T_c are of the order of 100 mK and the response times are of the order of 20-100 μs.

The spectral resolution depends on the slope of the superconducting transition (α), the critical temperature T_c and the heat capacitance of the device (C) via the expresion $\Delta E_{\mathrm{FWHM}} \propto T_c\sqrt{\frac{C}{\alpha}}$. Spectral resolutions of a few eV have been measured, being optimal in the keV range.

2.2 Specifications for EURECA

They were based on the expected requirements for the *High Resolution Instrument* for *XEUS*, namely:

- Spatially resolved non-dispersive spectroscopy
- A 5×5 sensor array, with a pixel size of 500 μm
- Spectral resolution of about 1 eV at 1 keV and 5 eV at 6 keV, optimized for "soft" energies (below 2 keV)
- Reading time of $\leq$100 μs
- Detection efficiency $>$90% in the range 1-3 keV

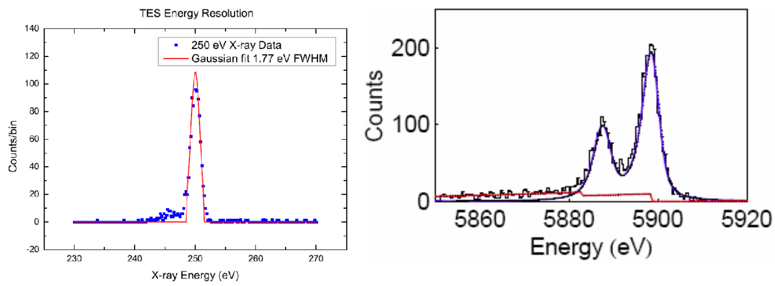

Fig. 3 Measured line profiles (left: synchrotron, right: MnKα), showing the energy resolution of one of the current EURECA sensors.

2.3 Recent progress in EURECA

Measurements in the BESSY synchrotron facility have shown an energy resolution of 1.8 eV, close to the requirements, albeit with only one pixel and with a non-optimized cryogenic device, using commercial LC filters.

The electronics (denominated EGSE) has been designed and is under development. The software has also been designed and it is in an advanced state of development [3]

Finally, the ADR (Adiabatic Demagnetization Refrigerator) is under development.

3 EURECA@Spain

The Spanish collaboration in EURECA is performing several tasks:

- Development and building of new superconducting bilayers based on MoAu
- Characterization of LC filters
- Software for data analysis and visualization (coordination and development of modules)

These efforts are financed by several projects: ESP2004-21934-E (IP: L. Fàbrega, ICMAB CSIC), ESP2003-16308-C02 (IPs: X. Barcons IFCA CSIC, L. Fàbrega ICMAB CSIC) and mat2005-02454 (IP: F. Bartolomé, ICMA CSIC).

3.1 Progress in new sensors

There is a continous development, building and characterization of superconducting bilayers based on MoAu, which seem to present a better performance after thermal tests than the TiAu bilayers used up to now in EURECA. These developments are in

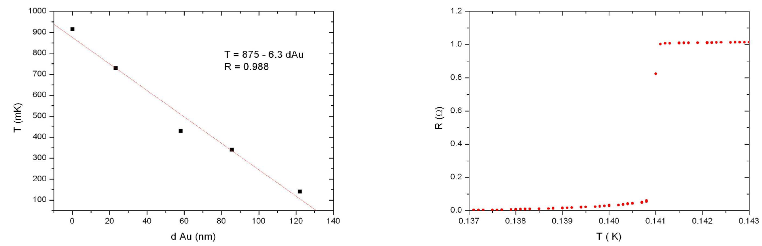

Fig. 4 Progress from EURECA@Spain. Left: critical temperature T_c versus width of the Au deposition in the MoAu bilayers, showing the progress towards $T_c \sim 100$ mK. Right: Resistance versus temperature for one of the MoAu bilayers.

the forefront in this field in Europe, since up to now the main progress has happened mainly in the US.

These bilayers are **extremely good** since they present very abrupt transitions, which translate in a good energy resolution. Their critical temperatures are $T_c \sim$100 mK, which would also help achieving a good energy resolution.

3.2 Progress in the software

With the advances in the hardware it is now becoming possible to define the general requirements for the software in terms of functionalities and data products. We are also defining the interfaces between the instrument data, the different processing chains for different types of data (science and charaterization) and the visualization of the data products.

The development includes a software repository with version control, to ensure a correct coordination of the different development teams. At the moment there are several processing chains implemented, including a prototype of an automatic pipeline to process the instrument data as they become available.

4 Conclusions

EURECA is a consortium in search of flying opportunities. The Spanish part of the consortium is more oriented towards science. EURECA brings together the most competent high-technology groups on on-board instrument design and development. This is a difficult endeavour, since it includes very busy people and many frontier projects, but at the same time is extremely rewarding, since we are breaking new ground.

The consortium is now in the R&D phase (pre phase A) with a lot of enthusiasm, despite the uncertainties introduced by the merging into *IXO*. If we move into the prototype phase we will need to involve the industry.

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