From Amps to eVs: the reconstruction process of the X-ray photons

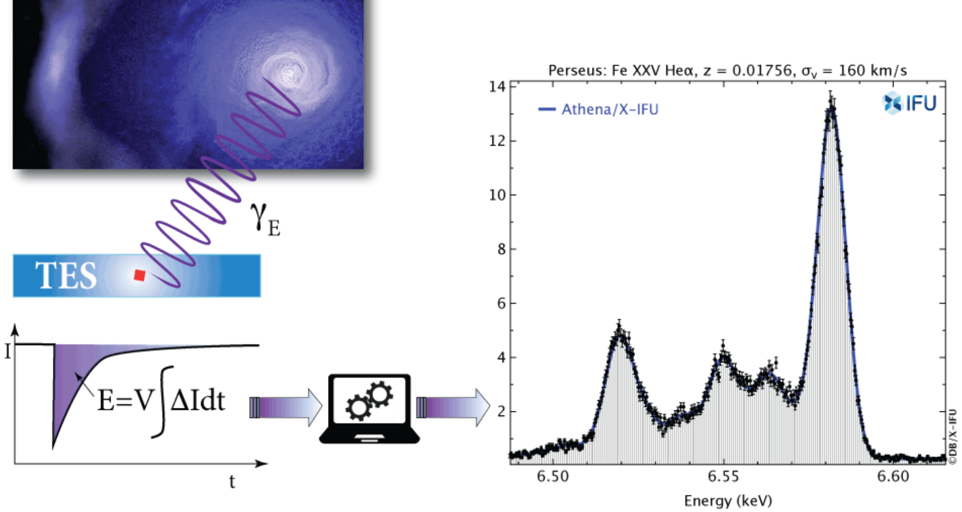
Maite Ceballos. Instituto de Física de CAntabria (IFCA), CSIC-UC, Spain, on behalf of the X-IFU event processing team

In the #AthenaNuggets 21, Simon Bandler described the technology of the Transition Edge Sensor (TES) at the core of the Athena X-ray Integral Field Unit (X-IFU) instrument: X-ray photon energy converted into heat converted into electrical pulses by means of an abrupt change in resistance in the superconductor electrical device. A simple detection principle that allows for an unprecedented energy resolution of 2.5 eV for energies up to 7 keV.

But astronomers do not want to deal with electrical pulses when they are analyzing their favourite source data, they need every photon credentials: arrival time, spatial position, and energy. And it is precisely here where the reconstruction software comes into play.

When an X-ray source is observed with the X-IFU, the Event Processor on board will be in charge of reading the electrical signal coming from the detector and extracting the scientific information. This processing step must be done on board due to limitations in telemetry and, on board, everything counts due to the limited processing resources. Thus, the first task of the processor is triggering the relevant information chunks of data, i.e., only those containing the pulses generated by the photons of the X-ray source.

Credit: Top left image, NASA/CXC/GSFC/S. Walker, ESA/XMM, ROSAT. Spectrum, X-IFU Consortium. Composition, ACO Team



The energy deposited by an X-ray photon is converted into a current pulse (left). Software algorithms on-board analyse the pulse and estimate the energy of the incoming photon to create a spectrum (right).

The algorithm used for the energy reconstruction of these incoming photons also has to be optimally dimensioned, a compromise between not being highly demanding in computational resources and providing energy resolution values fulfilling the science requirements.

For this purpose, the X-IFU team has been studying several algorithms (both for pulse detection and reconstruction) in terms of performance, computational cost, and calibration needs leading to a recently established baseline, but studies continue to get the best results for the detector final configuration.

This baseline algorithm is the Optimal Filter in Resistance Space, which is the simplest algorithm that best matches the requirements. It is also a simple concept: under the assumption that the detector is linear (all pulses have the same shape regardless of their energy and the pulse amplitude is the scaling factor) and that the noise is stationary, the pulse amplitude can be estimated by minimizing (in the noise-weighted least-squares sense) the difference between the data pulse and a pulse model (optimal filter) built during calibration. A low-cost improvement is obtained with an initial transformation of the signal, a proxy to the TES resistance which makes the signal more linear.

During the reconstruction process also the photon arrival time is estimated by means of the selected detection algorithm (also under trade-off). A final on-ground correction process for the energy and the arrival time of the photons needs to be performed so that at the end, astronomers at their desktops can study the broadening of spectral lines with an accuracy of 20 km/s or can finally fully understand the Warm-Hot Intergalactic Medium baryon budget (where the missing baryons are, what their detailed state is and how they are evolving). Amazing, isn't it?

www.the-athena-x-ray-observatory.eu ACO@ifca.unican.es @AthenaXobs Athena X-ray Observaroty