Scientific publications

July, 2024

The end-to-end simulator of the Athena X-IFU Cryogenic AntiCoincidence detector (CryoAC)

D'Andrea, Matteo ; Macculi, Claudio ; Lotti, Simone ; Piro, Luigi ; Argan, Andrea ; Minervini, Gabriele ; Torrioli, Guido ; Chiarello, Fabio ; Ferrari Barusso, Lorenzo ; Gatti, Flavio ; Rigano, Manuela

Abstract: The X-IFU is one of the two instruments of ATHENA, the next ESA large X-ray observatory. It is a cryogenic spectrometer based on an array of TES microcalorimeters. To reduce the particle background, the TES array works in combination with a Cryogenic AntiCoincidence detector (CryoAC). The CryoAC is a 4-pixel detector, based on ~1 cm2 silicon absorbers sensed by Ir/Au TES. It is required to have a wide energy bandwidth (from 20 keV to ~1 MeV), high efficiency (< 0.014% missed particles), low dead-time (< 1%) and good time-tagging accuracy (10 us at 1 sigma). An end-to-end simulator of the CryoAC detector has been developed both for design and performance assessment, consisting of several modules. First, the in-flight flux of background particles is evaluated by Geant4 simulations. Then, the current flow in the TES is evaluated by solving the electro-thermal equations of microcalorimeters, and the detector output signal is generated by simulating the SQUID FLL dynamics. Finally, the output is analyzed by a high-efficiency trigger algorithm, producing the simulated CryoAC telemetry. Here, we present in detail this end-to-end simulator, and how we are using it to define the new CryoAC baseline configuration in the new Athena context.

Read More on **ArXiv**

Scientific publications

June, 2024

Microcalorimeter Absorber Optimization for Athena and LEM

Wassell, Edward ; Adams, Joseph ; Bandler, Simon ; Chervenak, James ; Cumbee, Renata ; Finkbeiner, Fred ; Fuhrman, Joshua ; Hull, Samuel ; Kelley, Richard ; Kilbourne, Caroline ; Mateo, Jennette ; Muramatsu, Haruka ; Porter, Frederick ; Rani, Asha ; Sakai, Kazuhiro ; Smith, Stephen ; Wakeham, Nicholas ; Yoon, Sang

Abstract: High quantum efficiency (QE) X-ray absorbers are needed for future X-ray astrophysics telescopes. The Advanced Telescope for High ENergy Astrophysics (ATHENA) mission requirements for the X-ray Integral Field Unit (X-IFU) instrument dictate, at their most stringent, that the absorber achieve vertical QE > 90.6% at 7 keV and low total heat capacity, 0.731 pJ/K. The absorber we have designed is 313 μm square composed of 1.05 μm Au and 5.51 μm electroplated Bi films (Barret et al. in Exp Astron 55:373-426, 2023). Overhanging the TES, the absorber is mechanically supported by 6 small legs whose 5 μm diameter is tuned to the target thermal conductance for the device. Further requirements for the absorber for X-IFU include a > 40% reflectance at wavelengths from 1 to 20 μm to reduce shot noise from infrared radiation from higher temperature stages in the cryostat. We meet this requirement by capping our absorbers with an evaporated Ti/Au thin film. Additionally, narrow gaps between absorbers are required for high fill fraction, as well as low levels of fine particulate remaining on the substrate and zero shorts between absorbers that may cause thermal crosstalk. The Light Element Mapper (LEM) is an X-ray probe concept optimized to explore the soft X-ray emission from 0.2 to 2.0 keV. These pixels for LEM require high residual resistance ratio (RRR) thin 0.5 μm Au absorbers to thermalize uniformly and narrow < 2 μm gaps between pixels for high areal fill fraction. This paper reports upon technology developments required to successfully yield arrays of pixels for both mission concepts and presents first testing results of devices with these new absorber recipes.

More info on **Springer**

Scientific publications

June, 2024

Journal of Low Temperature Physics
Springer

Developments on Frequency Domain Multiplexing Readout for Large Arrays of Transition-Edge Sensor X-ray Micro-calorimeters

Vaccaro, D. ; Akamatsu, H. ; Gottardi, L. ; de Wit, M. ; Bruijn, M. P. ; van der Kuur, J. ; Nagayoshi, K. ; Taralli, E. ; Ravensberg, K. ; Gao, J. -R. ; den Herder, J. W. A.

Abstract: At SRON, we have been developing X-ray TES micro-calorimeters as backup technology for the X-ray Integral Field Unit (X-IFU) of the Athena mission, demonstrating excellent resolving powers both under DC and AC bias. We also developed a frequency-domain multiplexing (FDM) readout technology, where each TES is coupled to a superconducting band-pass LC resonator and AC biased at MHz frequencies through a common readout line. The TES signals are summed at the input of a superconducting quantum interference device (SQUID), which performs a first amplification at cryogenic stage. Custom analog front-end electronics and digital boards take care of further amplifying the signals at room temperature and of the modulation/demodulation of the TES signals and bias carrier, respectively. We report on the most recent developments on our FDM technology, which involves a two-channel demonstration with a total of 70 pixels with a summed energy resolution of 2.34 ± 0.02 eV at 5.9 keV without spectral performance degradation with respect to single-channel operation. Moreover, we discuss prospects towards the scaling-up to a larger multiplexing factor up to 78 pixels per channel in a 1-6 MHz readout bandwidth.

Read more on **ArXiv**

Scientific publications

June, 2024

Astronomy & Astrophysics

Toward mapping turbulence in the intra-cluster medium. III. Constraints on the turbulent power spectrum with Athena/X-IFU

Beaumont, S. ; Molin, A. ; Clerc, N. ; Pointecouteau, E. ; Vanel, M. ; Cucchetti, E. ; Peille, P. ; Pajot, F.

Abstract: Context. Future X-ray observatories with high spectral resolution and imaging capabilities will enable measurements and mappings of emission line shifts in the intracluster medium (ICM). Such direct measurements can serve as unique probes of turbulent motions in the ICM. Determining the level and scales of turbulence will improve our understanding of the galaxy cluster dynamical evolution and assembly, together with a more precise evaluation of the non thermal support pressure budget. This will allow for more accurate constraints to be placed on the masses of galaxy clusters, among other potential benefits.

Aims: In this view, we implemented the methods presented in the previous instalments of our work to characterising the turbulence in the intra-cluster medium in a feasibility study with the X-ray Integral Field Unit (X-IFU) on board the future European X-ray observatory, Athena.

Methods: From idealized mock observations of a toy model cluster, we reconstructed the second-order structure function built with the observed velocity field to constrain the turbulence. We carefully accounted for the various sources of errors to derive the most realistic and comprehensive error budget within the limits of our approach. With prior assumptions on the dissipation scale and power spectrum slope, we constrained the parameters of the turbulent power spectrum model through the use of Markov chain Monte Carlo (MCMC) sampling.

Results: With a very long exposure time, a favourable configuration, and a prior assumption of the dissipation scale, we were able to retrieve the injection scale, velocity dispersion, and power spectrum slope, with 1σ uncertainties for better than 15% of the input values. We demonstrated the efficiency of our carefully set framework to constrain the turbulence in the ICM from high-resolution X-ray spectroscopic observations, paving the way for more in-depth investigation of the optimal required observing strategy within a more restrictive observational setup with the future Athena/X-IFU instrument.

Read more on **ArXiv**

Scientific publications

May, 2024

IOPscience

Qualification and test of space compatible superconducting current leads (REBCO) designed for adiabatic demagnetization refrigerators

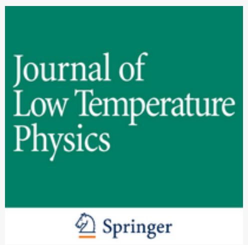
Duval, J. M. ; Prouvé, T. ; Collier-Wright, M. ; Drechsler, A. ; Hindley, D. ; La Rosa Betancourt, M. ; Kroll, R. ; Branco, M. ; Orgaz Diaz, D. ; Schlachter, S. I.

Abstract: Many astrophysics observations require space telescopes, either to reduce atmospheric perturbation or simply to make these detections possible (in the X-Ray spectrum for example). One of these missions, Athena, is led by the European Space Agency (ESA), with additional international contributions, dedicated to X-Ray observation. Two instruments will be part of this mission and among them, X-IFU, will use Transition Edge Sensors (TES) to detect and precisely measure the energy of X-Ray photons. These sensors require a temperature of 50 mK to reach their ambitious sensitivity goals. In space, this temperature can be reached using Adiabatic Demagnetization Refrigeration (ADR) and such a cooling system is currently being developed for the X-IFU instrument. ADR utilizes magnetocaloric materials which, upon variation in magnetic fields, can produce a cooling effect. The magnetic field of the order of 1 T in a volume of 10s of cm3 is produced by a superconducting coil with high winding number and current limited to approximately 2 A. Even though this current is low compared to most earth-based systems, metallic current leads to link the high- and low-temperature stages would cause high thermal loads, unacceptable for the limited capacity of the cryogenic cooling chain of the spacecraft. Therefore, a harness consisting of superconducting current leads is planned to reduce the thermal loads at the low-temperature stage. As part of an ESA contract, our team designed, built and tested such a space-compatible harness. This harness includes the electrical interfaces at both ends as well as mechanical support. Its development is capable of operating between interfaces at 80 K and 4 K. The harness is based on industrially available Rare-Earth-Barium-Copper-Oxide (REBCO) High-Temperature Superconductor (HTS) tapes. The tapes were laser-cut by our group to fulfill our specifications, Parylene coated and reinforced with Kapton laminate tape for mechanical and insulating purposes. After characterization of the single tapes, the assembled harness has been subjected to an extensive qualification sequence including thermal cycling and mechanical testing based on launch loads requirements. This paper will summarize the technical design choices for this HTS harness. It will discuss the test results and propose some perspectives for the next iteration of the development.

Read more on **IOP Science**

Scientific publications

May, 2024



Advanced Energy Scale Correction Techniques for the X-ray Transition Edge Sensors of the Athena mission

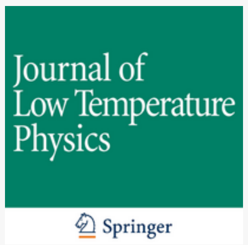
Cucchetti, E. ;Smith, S. J. ; Witthoeft, M. C. ; Eckart, M. ; Pajot, F. ; Peille, P. ; Porter, F. S.

Abstract: The X-ray Integral Field Unit (X-IFU) onboard the future European X-ray telescope Athena will be the first space instrument carrying an array of more than a thousand transition edge sensors. One of the key challenges of the X-IFU is the measurement of narrow X-ray atomic lines to determine velocity shifts at an unprecedented level of accuracy. For this reason, the energy scale of the instrument needs to be known with extreme accuracy, of 0.4 eV (1σ) up to 7 keV. The energy scale will be measured on the ground through a dedicated calibration campaign using fiducial X-ray sources. Though calibrated, the energy scale is extremely sensitive to the environmental conditions around the TES array, and drifts in the readout chain electronics. Uncorrected, the energy scale can naturally drift up to hundreds of eVs. Changes of the TES gain will be monitored via onboard X-ray calibration sources, and the energy scale will be corrected either per pixel, or within a small groups of pixels. Although simulations show that a 0.4 eV level can be achieved, the very high accuracy required by the X-IFU calls for experimental validation. A dedicated measurement campaign has been performed by NASA Goddard Space Flight Center to characterize the energy scale of a prototype kilo-pixel array of X-IFU-representative TESs. The analysis of the data demonstrated the ability to correct for various drifts using two fiducial lines to track the temporal gain variation. In this paper, we propose to extend this study on the same data set by investigating multi-parameter correction techniques based on both the pulse-height of the fiducial line and the prepulse baseline level, using the knowledge of the TES energy scale at reference temperature/magnetic field set points acquired on the ground. Investigations on the co-adding of pixels to perform a joint correction over pools of pixels is also explored.

More info on **Springer**

Scientific publications

May, 2024



System Performance of a TDM Test-Bed with Long Flex Harness Toward the New X-IFU FPA-DM

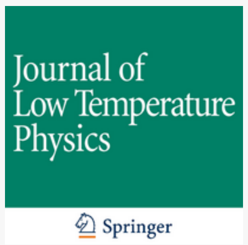
Vaccaro, D. ; de Wit, M. ; van der Kuur, J. ; Gottardi, L. ; Ravensberg, K. ; Taralli, E. ; Adams, J. ; Bandler, S. R. ; Chervenak, J. A. ; Doriese, W. B. ; Durkin, M. ; Reintsema, C. ; Sakai, K. ; Smith, S. J. ; Wakeham, N. A. ; Jackson, B. ; Khosropanah, P. ; Gao, J. -R. ; den Herder, J. W. A. ; Roelfsema, P.

Abstract: SRON (Netherlands Institute for Space Research) is developing the focal plane assembly (FPA) for Athena X-IFU, whose demonstration model (DM) will use for the first time a time domain multiplexing (TDM)-based readout system for the on-board transition-edge sensors (TES). We report on the characterization activities on a TDM setup provided by NASA goddard space flight center (GSFC) and national institute for standards and technology (NIST) and tested in SRON cryogenic test facilities. The goal of these activities is to study the impact of the longer harness, closer to X-IFU specs, in a different EMI environment and switching from a single-ended to a differential readout scheme. In this contribution we describe the advancement in the debugging of the system in the SRON cryostat, which led to the demonstration of the nominal spectral performance of 2.8 eV at 5.9 keV with 16-row multiplexing, as well as an outlook for the future endeavors for the TDM readout integration on X-IFU's FPA-DM at SRON.

Read More on **ArXiv**

Scientific publications

May, 2024



Impedance Matching Between SQUID and Warm Amplifier for TES Readout in TDM for the Athena X-IFU Instrument

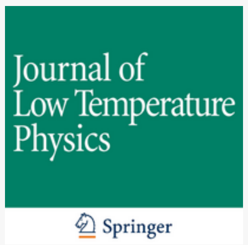
Gonzalez, Manuel ; Parot, Yann ; Prele, Damien ; Kirsch, Christian ; Cucchetti, Edoardo ; Peille, Philippe ; Murat, David ; Ravera, Laurent ; Van der Kuur, Jan

Abstract: Current cryogenic instruments require an increasingly high number of superconducting detectors. Large multiplexing factors are thus needed, increasing the bandwidth of the readout signals. In the specific case of transition edge sensors (TES), a cold amplification stage using superconducting quantum interference devices is usually coupled to a room temperature low-noise amplifier (LNA). A resistive harness up to a few meters long connects these two stages carrying signals with bandwidth of up to a few tens of MHz. In this context, it is reasonable to consider the possibility of impedance matching at the input of the LNA. In this paper, we present the impact of such impedance matching for the ATHENA X-IFU instrument, which uses TES in time-division multiplexing (Barret in Exp Astron 55:373-426 2023).

More info on **Springer**

Scientific publications

May, 2024



The Cryo-Harness Technology for the Athena X-IFU Detection Chain

Geoffray, H. ; Adams, J. ; Fossecave, H. ; Cucchetti, E. ; Bellouard, E. ; Peille, P. ; Daniel, C. ; Maisonnave, O. ; Guilhem, E. ; Jolly, A. ; Maussang, I. ; Jackon, B. ; Bandler, S. ; Doriese, B. ; Durkin, M. ; van der Kuur, J. ; van Leeuwen, B. J. ; Kiviranta, M. ; Prêle, D. ; Ravera, L. ; Parot, Y.

Abstract: CNES (French Space Agency) is in charge of the development of the X-ray Integral Field Unit (X-IFU) instrument for Athena, the high resolution X-ray spectrometer of the ESA Athena X-ray Observatory. X-IFU will deliver spectra from 0.2 to 12 keV with a spectral resolution in the range of 2.5 eV up to 7 keV on a 5'' pixels, with a field of view > 4' equivalent diameter. The main sensor array detection chain is a key part of the instrument, being by far the main contributor to its performance. It involves major partners: NASA GFSC, NIST, SRON, VTT, APC, and IRAP. The cryo-harness interconnecting the Focal Plane Assembly cold interface to the Warm Front End Electronics is under CNES responsibility. The different technical solutions are the loom technology and the shielded twisted pair technology. Characterizations have been performed on breadboards to assess the crosstalk performances for each solution. The results of these analysis are a driver to perform the trade-off between the available cryo-harness technologies.

More info on **Springer**