Lumière (Latest Upgraded Methodologies for the Investigation of X-Ray Emitting sources)

Rapport sur les contributions

https://indico.ijclab.in2p3.fr/e/11870

ID de Contribution: **2** Type: **Non spécifié**

Simulation-based inference for X-ray spectral fitting

mercredi 14 janvier 2026 11:45 (30 minutes)

In this paper, I will introduce simulation-based inference for X-ray spectral fitting, emphasizing on its application to the challenging newAthena mock X-IFU high-resolution X-ray spectra. Training a neural density estimator on dimension reduced spectra, computed either through a compact and light encoder or an embedding network enables to quickly derive posterior approximates. I will then describe how the approximate posterior estimates can be corrected by the known likelihood, via importance-resampling, to generate an asymptotically exact estimate of the posteriors, identical to the ones produced by BXA, yet within a run time at least an order of magnitude shorter.

Auteur: BARRET, Didier (IRAP)

Co-auteur: DUPOURQUÉ, Simon (Institut de Recherche en Astrophysique et Planétologie)

Orateur: BARRET, Didier (IRAP)

ID de Contribution: **3** Type: **Non spécifié**

Lessons learnt on background modeling and MCMC spectral fitting in the CHEX-MATE project

mardi 13 janvier 2026 12:00 (15 minutes)

The *Cluster HEritage project with XMM-Newton - Mass Assembly and Thermodynamics at the End-point of structure formation* (CHEX-MATE) is a multi-year Heritage program focused on studying 118 galaxy clusters, identified as the ultimate products of structure formation. This extensive analysis, encompassing over 6 Msec of XMM-*Newton* data, recently concluded with the application of a physically-motivated particle background model to the full dataset. This model was developed through the comprehensive study of more than 20 years of archival XMM-observations. My presentation will delve into the critical lessons learned regarding XMM-*Newton*'s particle background and its application to astrophysical spectra within a Bayesian framework, utilizing XSPEC MCMC spectral fitting.

Auteur: Dr ROSSETTI, Mariachiara (INAF - IASF Milano)

Orateur: Dr ROSSETTI, Mariachiara (INAF - IASF Milano)

ID de Contribution: **5** Type: **Non spécifié**

Quantifying the Spectacular - Applying Power-Spectral Analysis to X-ray Images of Supernova Remnants

mardi 13 janvier 2026 11:30 (15 minutes)

Since the advent of high-resolution X-ray imaging with modern CCD detectors, multi-band images of bright supernova remnants (SNRs) have stunned us with their beauty. While the spectral properties of such SNRs have been studied in detail with complex models, the spatial morphologies are frequently described qualitatively, but not quantified.

In this talk, I will discuss the potential of multi-band morphological analysis of SNRs using spatial correlation analysis. This includes auto- and cross-correlation functions within and between energy bands, and the corresponding power spectra. These tools can quantify the typical spatial scales of shocks, filaments, and ejecta clumps in bright SNRs.

While hydrodynamic simulations of SNRs typically require significant fine-tuning to match observed morphologies, these statistical descriptors can provide more immediate, quantitative tests to such models. This approach therefore complements the well-established spectroscopic diagnostics, offering new perspectives on the physical processes shaping SNRs, such as turbulence or explosion asymmetries.

Auteur: MAYER, Martin (Dr. Remeis-Observatory Bamberg (ECAP/FAU))

Orateur: MAYER, Martin (Dr. Remeis-Observatory Bamberg (ECAP/FAU))

ID de Contribution: **6** Type: **Non spécifié**

Challenges of extended sources analysis with XRISM

lundi 12 janvier 2026 10:30 (30 minutes)

With its 5 eV resolution (a factor >20 compared to CCD spectrometers), the Resolve instrument onboard XRISM marks the beginning of the high-resolution X-ray spectroscopy era. This achievement is particularly transformative for extended sources, where the non-dispersive characteristics of Resolve (and future micro-calorimeters such as NewAthena/X-IFU) allow for the first time to probe the dynamics of astrophysical plasmas such as supernova remnants and clusters of galaxies. In practice, however, the analysis of extended sources with Resolve is rendered challenging because the large point spread function (PSF, ˜1.3 arcmin) of the telescopes mixes photons (thus spectral information) coming from different regions of the sky. In this talk, we discuss this "spatial-spectral mixing" challenge and concrete methods to mitigate it. We conclude by addressing future prospects such as extended source analysis expected on NewAthena/X-IFU.

Auteur: MERNIER, François (IRAP)

Orateur: MERNIER, François (IRAP)

ID de Contribution: **7** Type: **Non spécifié**

Pinpointing pure-metal ejecta X-ray emission in supernova remnants with NewAthena

mercredi 14 janvier 2026 11:15 (15 minutes)

Spectral analysis of X-ray emission from ejecta in supernova remnants (SNRs) is hampered by the low spectral resolution of CCD detectors, which typically creates a degeneracy between the best-fit values of chemical abundances and the plasma emission measure. The combined contribution of shocked ambient medium and ejecta to the emerging X-ray emission further complicates the determination of the ejecta mass and chemical composition. This degeneracy leads to big uncertainties in mass estimates and can introduce a bias in the comparison between the ejecta chemical composition derived from the observations and the yields predicted by explosive nucleosynthesis models. An analogous degeneracy between the nonthermal and thermal continuum emission hampers precise estimates of the X-ray thermal and nonthermal fluxes in regions close to the shock fronts.

We explored the capabilities of newAthena/XIFU on identifying a spectral feature that may allow us to discriminate between metal-rich and pure-metal plasmas in X-ray spectra of SNRs. We investigated spectral features of bremsstrahlung, radiative recombination continua (RRC), and line emission, by exploring a wide range of chemical abundances, plasma temperatures, and ionisation parameters.

We then synthesized NewAthena/XIFU spectra from a state-of-the-art 3D hydrodynamic simulation of Cas A and identified the southeastern Fe-rich clump of Cas A as an ideal target to apply our diagnostic tool. The analysis of the synthetic spectra highlights that a bright RRC shows up in the spectra when the plasma is made of pure-metal ejecta and a comparison with the current CCD spectra clearly shows how such feature is

missed because of the low spectral resolution. Thanks to NewAthena, we will be able to pinpoint the presence of pure-metal ejecta in the X-ray spectra of SNRs, critical to recover the absolute mass and chemical composition of the ejecta. Moreover, we found that thanks to the superior spectral resolution we will significantly improve the constraints on the thermal emission parameters retrievable from emission lines diagnostic enabling a more precise estimate of the nonthermal-to-thermal flux ratio.

Auteur: GRECO, Emanuele (INAF - Osservatorio Astronomico di Palermo)

Orateur: GRECO, Emanuele (INAF - Osservatorio Astronomico di Palermo)

ID de Contribution: **8** Type: **Non spécifié**

Synthetic X-ray Spectra from 3D MHD Simulations: The Case of SN 1987A

mardi 13 janvier 2026 10:15 (15 minutes)

We present an in-house developed tool for synthesizing high-resolution thermal X-ray spectra from three-dimensional magneto-hydrodynamic (MHD) simulations of supernova remnants (SNR). Our approach translates directly the physical quantities predicted by MHD models, such as temperature, density, ionization timescale, and velocity fields, into observable spectra for current and future telescopes, incorporating both Doppler and thermal broadening effects. Using SN 1987A as a case study, we exploit state-of-the-art MHD simulations that follow the system's evolution from the core-collapse phase to its current remnant stage. The synthetic spectra allow for a quantitative prediction of line profiles, distinguishing the contributions of shocked ejecta and circumstellar material. The resulting synthetic spectra reproduce key features such as line broadening and blending, providing a diagnostic framework to infer ejecta dynamics and composition from high-resolution X-ray observations. The methodology outlined here establishes a reproducible pathway for connecting MHD simulations with observational data, advancing the interpretive power of spectroscopic diagnostics in high-energy astrophysics.

Auteur: SAPIENZA, Vincenzo (INAF - Osservatorio Astronomico di Palermo)

Orateur: SAPIENZA, Vincenzo (INAF - Osservatorio Astronomico di Palermo)

ID de Contribution: **9** Type: **Non spécifié**

Using Simulation Based Inference for inferring turbulence in galaxy clusters

mercredi 14 janvier 2026 11:30 (15 minutes)

The X-IFU on board NewAthena will allow precise mapping of turbulent velocity fields inside the intra-cluster medium. The inference of the properties of the underlying turbulence field needs to take into account sample variance, the fact that each field is a unique finite sized realization. Simulation Based Inference is well suited to tackle this problem. In this talk, I will present how I used SBI to infer turbulent parameters from an ideal observation of a galaxy cluster with X-IFU/NewAthena.

Auteur: MOLIN, Alexeï (IRAP)

Orateur: MOLIN, Alexeï (IRAP)

ID de Contribution: **10** Type: **Non spécifié**

A Simulation Framework for Synthetic X-ray Observations with NewAthena

mercredi 14 janvier 2026 11:00 (15 minutes)

We present a simulation framework developed to evaluate the capability of the NewAthena mission, but easily adaptable to other missions as well, to detect and characterize diffuse X-ray emission, focusing on reproducing realistic instrument performance and consolidated X-ray analysis tools.

Synthetic observations were generated starting from map simulations, which were converted into mock X-ray event lists through SIXTE and SIMPUT. Instrumental effects such as vignetting, PSF broadening, detector background, and point source confusion were included using the latest WFI and X-IFU response matrices and calibration files. The simulated data were then processed with tools currently used in the X-ray astronomy.

Auteur: BARTALUCCI, Iacopo (INAF-IASF Milano)

Orateur: BARTALUCCI, Iacopo (INAF-IASF Milano)

ID de Contribution: **11** Type: **Non spécifié**

A Variational Auto-Encoder to classify & explore the XMM-Newton archive

mardi 13 janvier 2026 12:15 (15 minutes)

Ever since X-ray observatories have started to probe the Universe, one of the objectives has been to classify the observed sources. Indeed, the X-ray sky is extremely diverse, with emission coming from stellar atmospheres, to super-massive black holes, up to galaxy clusters. It remains challenging to conduct extensive studies of all the detected sources due to the considerable volume of data that needs to be analyzed. For instance, most of the classification work has been supervised, meaning sources have been sorted in human-decided categories, based on their properties. These categories can be somewhat arbitrary, and will also be challenged by future missions probing new, never-before-seen depths of the Universe.

The work presented here is an attempt at unsupervised classification of the entire XMM-Newton archive. For this purpose, we apply a Variational Auto-Encoder (VAE) architecture to the EPIC pn spectra of each detection. Studying the latent space of the VAE allows us to dramatically reduce the dimensionality of the classification problem, down to the (relatively low) dimension of the latent space. We can then analyse how these objects scatter in latent space, how they tend to cluster with similar objects, and how they evolve over time through latent trajectories. While this is still a work in progress, we prove the potential of this method in both unsupervised classification, as well as possible applications in similarity search, or in outlier detection.

Auteur: QUINTIN, Erwan (European Space Agency)

Co-auteur: DUPOURQUÉ, Simon (Institut de Recherche en Astrophysique et Planétologie)

Orateur: QUINTIN, Erwan (European Space Agency)

ID de Contribution: **12** Type: **Non spécifié**

First look at Vela X-1 with XRISM

mardi 13 janvier 2026 10:00 (15 minutes)

The spectral and timing behaviour of neutron star high-mass X-ray binaries (HMXBs) offers a unique opportunity to investigate accretion onto compact objects and the wind structures of massive stars. In particular, understanding the X-ray emission from neutron stars is a critical topic of research for current and future astrophysical studies, as highlighted by its prominence in the science cases of the upcoming NewAthena mission. In our study, we focus on an observation of the key source Vela X-1, which was obtained during the first cycle of the Guest Observer programme of XRISM when the neutron star was in inferior conjunction. We also present results obtained simultaneously with the XMM-Newton and NuSTAR observatories. This exceptional dataset enables high-resolution broadband spectroscopy of Vela X-1, covering the energy range from 0.5 to 79 keV. The Resolve spectrometer onboard XRISM reveals for the first time the doublet of the emission lines of FeKα1 and FeKα2 as well as NiKα. Additionally, we investigate the clumpy structure of the material being accreted by the neutron star with an in-depth view into the accretion and photoionisation wakes, and provide valuable data for cross-calibration studies among three of the most modern and widely used X-ray telescopes. The analysis was performed with the jaxspec X-ray spectral fitting library, which allowed the fit parameters to remain free to vary by employing variational inference with a multivariate Gaussian guide for the posteriors –an approach not possible with classical frameworks.

Auteur: DIEZ, Camille (ESA/ESAC)

Co-auteurs: QUINTIN, Erwan (European Space Agency); ZHOU, Menglei (Universität Tübingen); DUPOURQUÉ, Simon (Institut de Recherche en Astrophysique et Planétologie)

Orateur: DIEZ, Camille (ESA/ESAC)

ID de Contribution: **13** Type: **Non spécifié**

XRISM analysis of supernova remnant Cassiopeia A: Bayesian study with UltraSPEX

lundi 12 janvier 2026 12:15 (15 minutes)

Cassiopeia A (Cas A) is the youngest known galactic core-collapse supernova remnant (SNR) and is perhaps the best-studied SNR in X-rays. Cas A was observed at two different locations by XRISM, the X-Ray Imaging and Spectroscopy Mission, for more than a total of 350 ks. This rich dataset has revealed unprecedented details in elemental abundances, their dynamics, and plasma properties. In this talk, I will share the latest XRISM results on mapping the stellar ejecta kinematics and plasma properties of Cas A. I present the challenges faced during the analysis of high-resolution XRISM data, which required updates to atomic databases and Bayesian-based fitting methods. To this end, we developed UltraSPEX —a new tool integrating the nested sampling algorithm Ultranest with SPEX spectral fitting software, which offers unique computational advantages for fitting high-resolution XRISM/Resolve data.

Auteur: AGARWAL, Manan (University of Amsterdam)

Co-auteurs: VINK, Jacco; GU, Liyi; PLUCINSKY, Paul

Orateur: AGARWAL, Manan (University of Amsterdam)

ID de Contribution: **14** Type: **Non spécifié**

Dendrogram clustering and quantum extreme learning for the study of supernova remnants images and optically-thin X-ray spectra

mardi 13 janvier 2026 11:45 (15 minutes)

I report on preliminary results from a collaborative project between the Supernova Remnants and Cosmic Ray Group, the Observatory of Complex Systems Group, and the Quantum Theory Group at the University of Palermo.
By adopting different dendrogram-based techniques, we developed a tool to quantitatively measure the similarities among different narrow-band images of a supernova remnant and of different supernova remnants. We tested our tool on Chandra observations of Cassiopeia A, Tycho's SNR, Kepler's SNR, W49B, and G292.0+01.8. We identified clusters of different chemical elements in Type Ia and core-collapse remnants and obtained interesting clues on the origin of W49B.
I also present the methodology we developed to adopt Quantum Extreme Learning Machines for the retrieval of the best-fit parameters of optically-thin X-ray spectra. I will show preliminary results obtained by using a real quantum computer as a reservoir for the training of the deep learning algorithm.

Auteur: MICELI, Marco (Department of Physics and Chemistry E. Segrè, University of Palermo)

Orateur: MICELI, Marco (Department of Physics and Chemistry E. Segrè, University of Palermo)

ID de Contribution: **15** Type: **Non spécifié**

SUSHI science

vendredi 16 janvier 2026 11:45 (15 minutes)

SUSHI is a new algorithm for fitting the spatial distribution of spectral parameters within extended X-ray emitting structures. In this talk, I will present two examples of the implementation of SUSHI to pulsar wind nebulae and AGN jets. Not only does SUSHI identify trends that were previously hidden, it also defines regions of particular interest. In this way, it allows us to investigate the physics driving spectral changes without the bias of fitting individual pixels, or the counts-based selection from Voronai tessellation.

Auteur: BOGENSBERGER, David (CEA Saclay)

Co-auteurs: Dr ACERO, Fabio (AIM, CEA, CNRS, Universite Paris-Saclay, Universite Paris); BALLET, Jean (AIM, CEA Saclay); Dr LASCAR, Julia

Orateur: BOGENSBERGER, David (CEA Saclay)

ID de Contribution: **16** Type: **Non spécifié**

Statistical Aspects of X-ray Spectral Analysis and BXA tutorial

jeudi 15 janvier 2026 09:30 (1 heure)

Fitting models to X-ray spectra is a fundamental technique to infer information about the hot and energetic universe. Finding credible parameter ranges for a given spectral model and dataset(s) however is not a simple task. In this workshop, we will first present the recommended practices for fitting models to X-ray spectra, including an overview of the instrumentation response, the linear modelling approximation, Poisson count statistics, the Gaussian approximation, data re-binning, visualisation techniques and handling backgrounds. We will then introduce the Bayesian X-ray Analysis (BXA) software package as a powerhouse for Bayesian parameter estimation, model checking and model comparison, capable of deriving parameter constraints effectively irrespective of model complexity or data quality. We will conclude with additional applications, such as the hierarchical generation of population distributions from a sample of parameter posteriors. Realistic hands-on example exercises with accompanying data files and code will be included to apply the theoretical concepts in practice.

Auteurs: BUCHNER, Johannes (MPE); BOORMAN, Peter (MPE)

Orateurs: BUCHNER, Johannes (MPE); BOORMAN, Peter (MPE)

ID de Contribution: **17** Type: **Non spécifié**

A simulation-based likelihood for X-ray surveys

vendredi 16 janvier 2026 11:30 (15 minutes)

How black holes accrete to super-massive monsters in centres of nuclear galaxies and in this luminous process impact galaxies is a key open question in galaxy evolution. The puzzle has remained in many pieces: Selection effects confuse, and most studies focus on two or three parameters. Yet, these indicate a multi-variate, probabilistic link between AGN accretion, obscuration, and the host galaxy's mass, star-formation, and morphology. A new window to cleanly select statistical samples to investigate these inter-dependencies opened with eROSITA. We aim to develop a scalable analysis of the X-ray to IR SED for millions of sources, to decode which host galaxies preferentially undergo a quasar phase and experience its energy release.
Starting from the known evolving galaxy population, we trigger AGN with parametric probabilistic distributions and generate X-ray survey samples. To generate galaxy-AGN fluxes with realistic errors, we use the new GRAHSP SED fitting engine, validated to retrieve host galaxy mass even in bright AGN. To feasibly compute survey likelihoods we introduce a new machine-learning-based survey likelihood, supported by an explicit generative model and advances in deep neural network models. The likelihood allows building extensible models. In our application, we explore the mass and star-formation-dependence of AGN triggering, jointly with the geometry of the AGN accretion engine.

Auteur: BUCHNER, Johannes (MPE)

Orateur: BUCHNER, Johannes (MPE)

ID de Contribution: **18** Type: **Non spécifié**

Investigating Deviations from Self-Similarity in a Sample of Massive Galaxy Clusters

mardi 13 janvier 2026 12:30 (15 minutes)

In a simple cold dark matter scenario, galaxy clusters are formed by hierarchical gravitational collapse of the dominant dark matter component. To the first order, this process is self-similar and scale-free. However, it is known that the thermodynamic properties of the hot gas deviate from those predicted by simple self-similar models, presumably due to the influence of non-gravitational processes. In this poster, we investigate the deviations from self-similar predictions of the thermodynamic profiles of a sample of 92 galaxy clusters selected through their Planck/SPT Sunyaev-Zeldovich effect (SZE) signal. The sample spans a mass range of
$M500 = [0.5, 2.0] \times 10^{14} M_{\odot}$, and lies at redshifts $0.05 < z < 1.13$. We measure the scaling of the thermodynamic properties (density, temperature, entropy, pressure) with mass and redshift, with associated uncertainties, as a function of distance from the cluster centre. The redshift scaling exhibit a clear deviation from self-similar predictions at distances r
$lesssim 0.5$
$R500$, reaching agreement with self-similar only around 1.0
$R500$. By describing the gas thermodynamic profiles using universal functional forms, we are able to better constrain the intrinsic scatter in the scaled profiles and compare our results with those reported in the literature.

Auteur: M. BARALDI, Edoardo (CEA-Paris Saclay)

Orateur: M. BARALDI, Edoardo (CEA-Paris Saclay)

ID de Contribution: **19** Type: **Non spécifié**

Registration and welcome coffee