Towards a 3D characterisation of X-ray extended sources

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Images et animations : www.github.com/facero/sujets2020

Context: With deep X-ray mega-second observations with XMM-Newton and Chandra (containing up to 100 millions photons), very high spectral resolution data from the Hitomi telescope and the Xrism and Athena satellites on the horizon, X-ray data are getting scientifically richer but increasingly complex to analyse. With a strong implication from the French community, the X-IFU instrument onboard the Athena telescope will combine high spectral and spatial resolution and will be a game changer in the X-ray spectro-imaging domain. Despite this huge improvement in instrumental performances, the development of the analysis methods have stalled in the last decades and are not ready to reveal the true wealth of information encoded in these rich datasets. Current methods are limited to 1D spectra or 2D images, and do not exploit the multi-dimensional nature (position, energy, and time being recorded for each event) of the X-ray data. In addition they are not efficient at correcting from geometrical projections effects and the disentangling of multiple physical components.

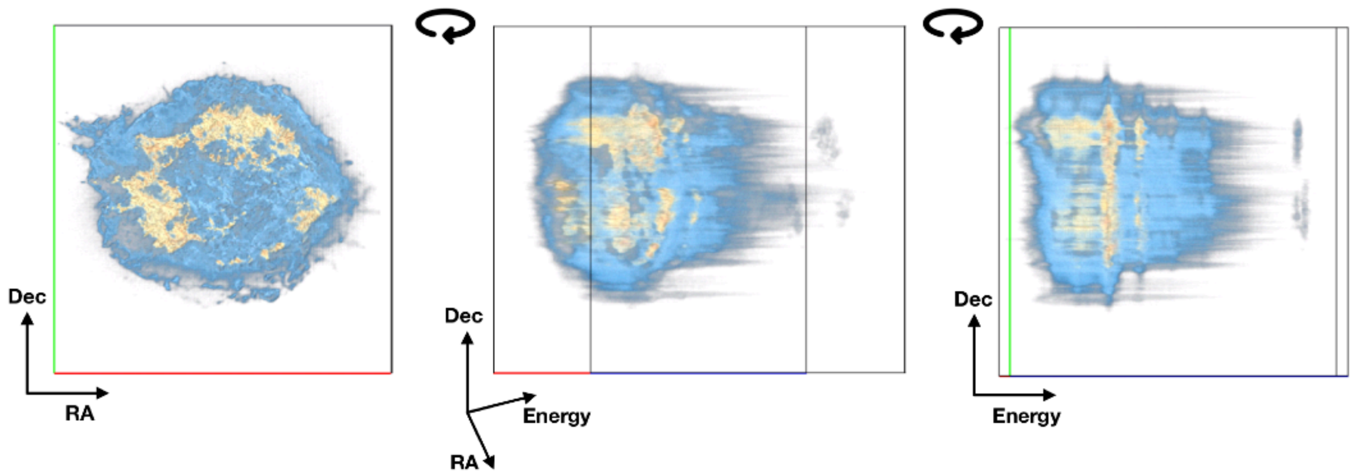

Figure 1: volume rendering of the supernova remnant Cassiopeia A X-ray data cube (RA, Dec, Energy). The colours indicate a higher density of X-ray photons. The face-on image (left panel) shows the spatial distribution of the X-ray emission and is comparable to classical images. Looking at the cube edge-on reveals a different facet of the object showing the distribution of heavy elements (Mg, Si, S, Fe, etc) via their line emission. The new analysis tools will be developed to take advantage of the multi-dimensional nature of the data.

Description of the project: we propose to transform the way X-ray data are analysed by capitalising on the expertise developed by the applied mathematics group in our laboratory; in particular in the blind source separation algorithms initially developed to separate the CMB map from the foregrounds in the Planck data. The method jointly exploits the morphological and spectral diversity of the data in the wavelet domain to separate the different astrophysical components and map their properties.

These new techniques allow to identify and characterise new, potentially unexpected, physical components in extended sources. A new branch of the method is currently being developed with an implementation of physically motivated models within a machine learning context (i.e. feature learning). This open the possibility to disentangle the physical component and deconvolve from projection effects at the same time and allowing mapping of quantities such as the velocity distribution of heavy elements in supernova remnants, or the temperature and abundances of the hot gas in clusters of galaxies in 3D (x, y, z).

In supernova remnants those new tools will be used by the PhD candidate to investigate what fingerprints supernovae leave in their remnant. As a matter of fact, the explosion mechanisms of Type Ia and core-collapse supernovae are still unclear but each explosion scenario has a specific ejecta fingerprint.
In this project, we will revisit the nature of the progenitors (core-collapse or Type Ia supernova) and the explosion mechanism via a detailed morphological analysis by mapping the 3D structures of the heavy elements in the remnants.
From a technical point of view, the PhD candidate will develop, adapt to an X-ray astronomy context, and apply these advanced techniques to data of increasing complexity. First we will test these methods on the archival data (XMM-Newton and Hitomi if possible). This will allow us to extract the full scientific potential of these data and in a second time to obtain more realistic models to build simulations for Athena and test the capacity of the methods on high spectral resolution data from X-IFU. This project will enhance the French scientific contribution to the Athena mission and in particular its ground segment by exploring new analysis tools.

Références:
Cosmic microwave background reconstruction from WMAP and Planck PR2 data; Bobin et al., 2016
Novel method for component separation of extended sources in X-ray astronomy; Picquenot, Acero, Bobin, Maggi, Ballet & Pratt, 2019.

Topics: X-ray astronomy, XMM-Newton, Athena, signal processing, blind source separation, physically motivated machine-learning clusters of galaxies, supernova remnants.