Summary

Pictor A, recognized as the archetypal powerful radio galaxy of the FR II type, is not only one of the brightest radio sources in the sky, but is also particularly prominent in the X-ray domain. Importantly, the extended structure of Pictor A is characterized by the large angular size of the order of several arcminutes. This structure could be therefore easily resolved by the modern X-ray telescopes, in particular by the *Chandra* X-ray Observatory. As such, Pictor A is a truly unique object among all the other radio galaxies. In the **Chapter 1** of this Dissertation, I introduce extensively the source, its history and its multi-wavelength emission, and provide basic information regarding the astronomical instruments (both ground-based telescopes as well as space-born satellites) capable of observing active galaxies and their nuclei (AGN), the phenomenology of active galaxies in general, or finally regarding the most fundamental radiative processes which are of importance in my research.

The main goal of my scientific research carried out during the last years in a collaboration with several colleagues and under the supervision of dr hab. Łukasz Stawarz, as summarized in this Dissertation, is a comprehensive and novel re-analysis of all the available archival *Chandra* data for Pictor A. One of the main difficulties in this respect, is that the *Chandra* observations spread over the past decades have targeted different regions in the source with various exposures and off-axis angles. In addition, those regions do vary dramatically in their X-ray output and appearance, from the extremely bright and point-like (unresolved) nucleus, to the low-surface brightness but considerably extended lobes.

Keeping in mind the above-mentioned difficulties and challenges, for each region within the Pictor A system and each pointing selected for the analysis, I studied in detail the *Chandra* point-spread function (PSF), and the background-subtracted emission spectrum within the $0.5 - 7.0$ keV range, performing, whenever possible, image deconvolution, timing analysis, and spectral modeling.

In particular, in my studies I have focused on the following three main research problems: **Chapter 2:** an approach to the X-ray spectroscopy of the active nucleus in Pictor A radio galaxy, carried out in a regime of a severe instrumental pile-up; **Chapter 3:** investigating the X-ray structure of the termination shocks of relativistic jets in Pictor A, the so-called "hotspots", by means of detailed image deconvolution and timing analyses; and **Chapter 4:** investigating correlations between the X-ray and radio emission features within the extended lobes of the source.

Our approach to the analysis of the *Chandra* data for the active nucleus in Pictor A radio galaxy, presented in Chapter 2, and in particular to the spectral analysis in a regime of a strong instrumental pile-up, is alternative to the approach presented in the literature so far. In particular, instead of analyzing the extended wings of the central PSF as typically per-

formed in such cases, we have utilized the updated pile-up model newly implemented in the modeling and fitting software `Sherpa`. There are differences between our analysis results and the results obtained before by the other authors, in particular regarding the slopes of the AGN power-law continuum, or the flux changes in the system. And while in the framework of our approach we were not able to completely remove/fully account for the instrumental pile-up effect, we nonetheless outlined the two main novel conclusions emerging from our analysis: (i) the contribution of the hot gaseous atmosphere of the host to the radiative output of the Pictor A nucleus, is very significant, and even dominates at distances of only several pixels from the center (up to ~ 30 px); as a result, one should be extremely careful when analyzing the extended wings of the central PSF in search of the AGN emission component free from the instrumental pile-up; (ii) the available *Chandra* data allow, formally, for the presence of the very broad fluorescent iron line in the nuclear spectrum of Pictor A; we however deem this extremely exciting possibility as rather unlikely, due to the fact that the "grade migration" in the piled-up detector is a more probable cause of the observed hard X-ray excess in the 0.5–7.0 keV *Chandra* spectra of the system.

In the Chapter 3 of the Dissertation, I present an analysis of the X-ray morphology and flux variability of the particularly bright and extended Western hotspot in Pictor A, based on data obtained with *Chandra*. The hotspot marks the position where the relativistic jet, that originates in the active nucleus of the system, interacts with the intergalactic medium, at hundreds-of-kiloparsec distances from the host galaxy, forming a termination shock that converts jet bulk kinetic energy to internal energy of the plasma. The hotspot is bright in X-rays due to the synchrotron emission of electrons accelerated to ultra-relativistic energies at the shock front. In our analysis, we make use of several *Chandra* observations targeting the hotspot over the last decades with various exposures and off-axis angles. For each pointing, we study in detail the PSF, which allows us to perform the image deconvolution, and to resolve the hotspot structure. In particular, the brightest segment of the X-ray hotspot is observed to be extended in the direction perpendicular to the jet, forming a thin, ~ 3 kpc-long, feature that we identify with the front of the reverse shock. The position of this feature agrees well with the position of the optical intensity peak of the hotspot, but is clearly off-set from the position of the radio intensity peak, located ~ 1 kpc further downstream. In addition, we measure the net count rate on the deconvolved images, finding a gradual flux decrease by about 30% over the 15-year timescale of the monitoring.

In the Chapter 4 of the Dissertation, I present detailed analysis of the distinct X-ray emission features present within the Eastern radio lobe of the Pictor A galaxy, around the jet termination region, utilising the data obtained from *Chandra*. Various emission features have been selected for the study based on their enhanced X-ray surface brightness when compared with the surroundings, including five sources that appear point-like, as well as three extended regions, one characterised by a filamentary morphology. For those, we perform a basic spectral analysis within the 0.5–7 keV range. We also investigate various correlations between the X-ray emission features and the non-thermal radio emission, utilising the high-resolution radio maps from the Very Large Array at GHz frequencies. The main novel findings following from our analysis, regard the newly recognized bright X-ray filament located upstream of the jet termination region, extending for at least three tens of kiloparsecs (projected), and inclined with respect to the jet axis, for which we observe a clear anti-correlation between the X-ray surface brightness and the polarized radio intensity, as well as a decrease in the radio rotation measure with respect to the surroundings. We speculate on the nature of the filament, in particular addressing a possibility that it is related to the presence of a hot X-ray emitting thermal gas, only partly mixed with the non-thermal radio/X-ray emitting electrons within the lobe, combined with the reversals in the lobe's net magnetic field.

All in all, my research summarized in this Dissertation, demonstrates an extraordinary richness of the *Chandra* X-ray Observatory archive, and at the same time an astonishing complexity of the physics behind the phenomenon of active galaxies. Together with my supervisor dr hab. Łukasz Stawarz, we sincerely hope that my effort directed into mastering the astronomical X-ray data analysis techniques, and in this way understanding better the X-ray emission of a particular active galaxy Pictor A, does provide a notable contribution to the modern high-energy astrophysics in general.