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Report on the Doctoral Thesis of M.Sc. Rameshan Thimmappa
entitled
„A Comprehensive and Novel Analysis of the *Chandra* X-ray Observatory Data for the Pictor A Radio Galaxy".

The reviewed dissertation describes a comprehensive re-analysis of the observational material on the powerful radio galaxy of the FRII type called Pictor A. The work is based on archival X-ray observations of this source made with the *Chandra* instrument and radio observations. The main difficulty in analyzing this observation material is that the *Chandra* observations spread over the past decades have targeted different regions in the source with various exposures and off-axis angles. However, the author of the work manages to successfully analyze this data again in a new way and examine the structure of the source with a very high accuracy.

The results of the research of M.Sc. Thimmappa on the source of Pictor A were published in three papers in which M.Sc. Thimmappa is the first author. These are, respectively: a conference report from a meeting organized by the International Astronomical Union *"Preliminary analysis of the X-ray emission from the central regions of the Pictor A"*, an already published peer-reviewed article in the Astrophysical Journal *"Chandra Imaging of the Western Hotspot in the Radio Galaxy Pictor A: Image Deconvolution and Variability Analysis"*, and an article sent for publication in that journal *"Complex Structure of the Eastern Lobe of the Pictor A Radio Galaxy: Spectral Analysis and X-ray/Radio Correlations"*. The percentage of the author's contribution to these works is around 50%. Additionally, Mr. Rameshan Thimmappa is also a co-author of another peer-reviewed article and a conference report on the CGCG 292-057 radio-loud galaxy observations made with the *Chandra* instrument. In summary, Mr. Thimmapp's entire publication output, amounting to five articles, is so far very fresh and small, but sufficient at this stage of his research career.

Mr. Thimmapp's doctoral dissertation has a clear, logical layout. The language is correct. It is divided into five chapters. It includes a table of contents, an extensive bibliography, a list of tables and figures, and relevant references to the literature. The first chapter of the dissertation is an introduction to the methods of observing space objects in various ranges of the electromagnetic spectrum, a brief description of the population of Active Galactic Nuclei and a description of the radiative processes encountered in these objects. A separate subsection is devoted to the *Chandra* X-ray

Observatory, which is understandable and useful due to the subject matter of the work. However, I miss a separate, short description of the phenomenon of 'pileup' that is inherent to CCD detectors, such as those that comprise the ACIS instrument on-board *Chandra* and is in fact the subject of the second chapter. The last section contains compilations of information on the observations of the galaxy Pictor A published so far by different authors. The knowledge presented in the first chapter comes from both textbooks and the latest scientific publications and shows the author's good understanding of the literature on the subject.

The main part of the dissertation are chapters two, three and four, which contain the author's original contribution to the aforementioned publications. The main goal of the presented work was the comprehensive and detailed study of the X-ray properties of galaxy Pictor A using a novel, alternative approach to the archival data. Thus, the second chapter describes a re-analysis of selected observations of active nucleus in Pictor A from the *Chandra* instrument. A new element in this analysis is the use of a numerical correction for the 'pileup' phenomenon called 'jdpileup'. As a result, it was established that the instrumental pile-up can affect also the extended wings of the central PSF. This is because the contribution of the hot gaseous atmosphere of the host to the radiative output of the Pictor A nucleus, is significant at distances of only several pixels from the center. However, the data do not clearly explain the high-energy excess seen in the modeled spectra of Pictor A nucleus.

The third chapter of the dissertation contains an analysis of the X-ray morphology and the flux variability of the Western hotspot in Pictor A, i.e. the place where relativistic particles from the jet interact with the intergalactic medium, creating shocks. A new thing in this analytical approach is the use of detailed PSF simulations and image deconvolution for the study. As a result of these analyzes, it was possible to resolve the components of the structure of the Western hotspot: the jet-like and disk-like features. These results were published in a peer-reviewed journal.

Finally, the fourth chapter contains the as yet unpublished results of the analysis of the distinct X-ray emission features present within the Eastern radio lobe of the Pictor A galaxy. Selected X-ray observations made with the *Chandra* instrument were reprocessed in a standard way within the 0.5 - 7 keV range. The new finding of this analysis is bright X-ray filament located upstream of the jet termination region. However, it is not clear to me why the previous standard analyzes of the archive observations of Eastern lobe failed to detect this component. Additionally the authors performed also the detailed studies of the radio surface brightness of the Eastern lobe and found 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.

Summarizing the main part of the dissertation, I state that the skills of the author of the dissertation in the field of data and image analysis are large, and the obtained results are important and interesting for the astronomical community.

I have no significant reservations as to the content and substantive quality of the dissertation. Some of the presented results have already been published in international astronomy journals, therefore reviewed by competent specialists. However, I have some comments on the thesis and I list them below in the order of their appearance in the text of the dissertation:

- I think that at the beginning of the dissertation, there should be summary in Polish.

- Chapter 1.2 should include a subsection describing the basics of the pileup phenomenon in the context of observations made with the *Chandra* instrument.

- The quality of some figures presented in the dissertation is poor, e.g. Figure 1.7, 1.9, 1.14.

- Figures on which radio maps are presented should contain information about the sensitivity (rms level) and the method of drawing contours. This is especially disturbing in Figure 4.3, where the two radio maps presented have different numbers of contours and their levels.

- Chapter 2.2.1, page 46, the author describes the changes of the flux of Pictor A nucleus using the Gregorian calendar, while in Figure 2.3 to which he refers, only the days of the Julian calendar are marked. This makes it difficult to follow this description. A similar situation occurs in Chapter 3 and it concerns Figure 3.3 and 3.11.

- Chapter 3.4, page 64, the PI of the observation program HST 13731 should be mentioned here.

- Chapter 4, the general comment to this chapter is that it should explain the differences in the approach to the analysis of the same observational materials used by other authors and the author of this dissertation, which led to the discovery of a new X-ray filament.

- Chapter 4.1, page 73 - 75, the text is a repetition of the basic information about Pictor A galaxy given earlier in Chapter 1.5 and it is redundant here.

- Chapter 4.1, page 75, the information about the assumed cosmology and definition of photon index is repeated here. I suggest that the assumed conventions should be mentioned once at the beginning of the dissertation.

- Chapter 4.3, page 80, I suggest that the secondary and primary hotspots described here should be clearly and visibly marked in Figure 4.3.

The above-mentioned shortcomings do not significantly affect the value of the dissertation presented for evaluation.

I conclude that the doctoral dissertation of Mr. Rameshan Thimmappa is an original solution to a scientific problem and meets all the usual and formal requirements for the PhD theses. Hence, I am applying for admission of M.Sc. Rameshan Thimmappa to further stages of the procedure, including the public defense.

Magdalena Kunert-Bajraszewska