NICOLAUS COPERNICUS UNIVERSITY

INSTITUTE OF ASTRONOMY

Mail address: ul. Gagarina 11, 87 – 100 Toruń, Poland

Tel. (+48 56) 611-30-03 fax: (+48 56) 611-30-09

Dr hab. Magdalena Kunert-Bajraszewska, prof. NCU
e-mail: magda@astro.uni.torun.pl
tel: +48 56 6113035

Toruń, 01.03.2022

Report on the Doctoral Thesis of M.Sc. Katarzyna Rusinek-Abarca
entitled
„Observational constraints on jet production efficiency in Active Galactic Nuclei".

The reviewed dissertation describes the studies of the radio jet production efficiency in Active Galactic Nuclei (AGN). Thus, this work is part of a long-lasting discussion in the scientific literature on the existence of the division of AGNs into radio-loud and radio-quiet objects and the nature of this possible division. The author of the work carries out a properly planned, original analysis of the jet production efficiency on the basis of specially selected samples of objects that come from articles and public databases. Ultimately, these theoretical considerations lead to the conclusion that not all AGNs are capable of producing strong radio jets, and the only model explaining the existence of jets with the highest strengths is the magnetically arrested disk (MAD) scenario.

The results of the research of M.Sc. Katarzyna Rusinek-Abarca were published in three peer-reviewed papers in which M.Sc. Katarzyna Rusinek-Abarca is the first author. The first two articles describe the analysis of the jet production efficiency for a few selected groups of AGNs. The third article describes how the fraction of radio-loud quasars in the AGN source population changes with redshift. The percentage of the author's contribution to these works is high and amounts to 70 - 80%. Additionally, Katarzyna Rusinek-Abarca is also a co-author of another three peer-reviewed articles about radio-loud and radio-quiet groups of AGNs. Summing up, the entire publication output of Katarzyna Rusinek-Abarca consists of six articles, which is a very good result at this stage of her career, and the articles themselves have already been noticed by the astronomical community.

Katarzyna Rusinek-Abarca's doctoral thesis consists of three scientific articles preceded by an introduction to the topic of active galactic nuclei with relevant references to the literature. The introduction provides a brief historical background and a general description of the AGN activity model. Section 1.3 briefly but sufficiently and clearly describes the properties of radio sources and the current theories concerning their evolution. Here, however, the author did not avoid some inaccuracies, although

while paying attention to it, I admit that the description of the AGNs is complicated and perhaps some hypotheses cannot be coherently combined into a short description. First of all, I would not confuse in one description the division of compact sources into GPS and CSS types with the division into CSO objects and, this name was not mentioned in the paper, MSO (medium-sized symmetric) objects. The first division is based on the shape of the radio spectrum and the second division is based on radio morphology. Indeed, CSOs are a subgroup of GPS sources, but I don't understand why CSOs in particular should be the smallest sources among AGNs. The author further explains that *"The small sizes of the above mentioned groups are explained as a result of: (1) their young age; (2) confinement of the jets by the surrounding medium; (3) their episodic activity…".* Meanwhile, I believe that points 1 and 3 are basically the same, assuming that each new phase of radio activity is actually a new radio source, and therefore a new compact structure with active jets. Additionally, points 2 and 3 try to explain the excess of compact radio sources visible in many sky surveys (recently from the LOFAR survey) and naturally connect the issue of the life cycle of a radio source with the topic of the jet production efficiency studied by the author. Recent research suggests that there is a jet-power dependent difference in the lifetime function of low-power and high-power sources, such that low-power sources are genuinely more short-lived. The author of the thesis could include such considerations in subsection '1.3.1.3 Evolution'. Later in the Introduction, Katarzyna Rusinek-Abarca presents a short review of the literature on radio loudness and presents selected basics of the physics of jets. In this part, the author states that *"In recent years many authors (Järvelä et al. 2017; Padovani 2017; Berton and Järvelä 2021) have been arguing that the radio loudness is inadequate and obsolete and that there is no astrophysical basis for using it to divide AGNs into RL, RI, and RQ classes. I state differently but only when relating the radio loudness parameter to the various mechanisms responsible for the radio emission in each of these groups."* I also share the author's opinion in this regard. And at the end of my assessment of the Introduction, I would like to note the lack of even a brief summary of the properties of AGNs in the field of X-rays. The author of the work herself points out that "*the only statistically significant difference between RL and RQ AGNs is the X-ray luminosity being a bit higher in RL group"* and this topic is directly related to the discussed issue of radio jets.

The main part of the dissertation are chapters two, three and four, which are original scientific articles published in very good international journals: Monthly Notices of the Royal Astronomical Society and Astrophysical Journal. The main goal of the presented articles was the extensive study of the jet production efficiency and the search for the mechanism responsible for this phenomenon and the division of AGNs into radio-loud and radio-quiet objects. In the first article, the analysis of radio and accretion properties of a large group of radio-loud AGNs confirmed the trend found earlier for another sample, namely decrease in the jet production efficiency at higher accretion rates. According to the authors, this result suggests that in the case of systems with high accretion rates, the accretion flows are expected to be radiatively efficient, and the production of such powerful jets may require an accretion scenario, which involves magnetically arrested discs (MADs). This, however, requires the presence of geometrically thicker accretion disks than standard theory predicts in these objects. This research is continued in the next article, which analyzes not only radio-loud objects but also sources classified as radio-intermediate and radio-quiet sources. Based on these analyzes, the authors draw an interesting conclusion about the existence of threshold conditions for the production of powerful jets. Again, the authors of the article suggest that *"such conditions can be associated with the formation of*

MADs and that only those AGNs that live longer than the time required to build up the MAD can become RL ". And finally, the third article, which shows a slightly different approach to the topic of the jet production efficiency, namely attempts to explain the increase in the fraction of radio-loud quasars with cosmic time using the MAD formation scenario.

Summing up, I believe that the articles by Katarzyna Rusinek-Abarca presented for evaluation discuss a very interesting idea explaining such a large diversity of radio properties of AGNs. What's more, they fit perfectly into the current discussion and analyzes of new, more sensitive radio surveys that suggest a different lifetime distribution or different jet physics for the less powerful radio objects. Recent studies of slow radio transients (on timescales <20 years, CNSS and VLAS surveys) also postulate the existence of some boundary conditions for the ignition of radio activity, understood as exceeding the radio loudness threshold. I also have no objections to the technical part of this work, i.e. the quality of the analyzes performed or the selection of samples. 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. As for the scheme of the doctoral dissertation, at the end I have a note about the lack of a short chapter summarizing the results obtained by the author in these three articles and suggestions for possible further analyzes that could constitute further arguments for the proposed MAD scenario.

I conclude that the doctoral dissertation of M.Sc. Katarzyna Rusinek-Abarca 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. Katarzyna Rusinek-Abarca to further stages of the procedure, including the public defense.

Magdalena Kunert-Bajraszewska