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Referee Report for the PhD Thesis of Maitrayee Gupta

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The PhD Thesis of Maitrayee Gupta titled **"Comparison of AGN properties in luminous radio galaxies to their ratio-quiet counterparts"** aims to find critical characteristics for an efficient production of relativistic jets in Active Galactic Nuclei (AGN). The title of the thesis does not fully reflect the importance of this research topic targeting the fundamental and still unanswered question of why only a small fraction of AGN generate jets, while the majority of AGN remain jetless and radio-quiet. Although the thesis does not resolve this longstanding issue, the results of the research constitute an important contribution to the progress of AGN studies.

AGN are powered by accretion onto a supermassive black hole and the unified AGN models show no dramatic differences between radio-quiet and radio-loud sources, except for the presence of a relativistic jet. What makes a jet when there is no obvious difference between these systems? This question has been asked many, many times and numerous studies have been performed over the years with no solution. Modern observational surveys now provide high quality data collected across the full range of the electromagnetic spectrum, presenting an opportunity to perhaps look for clues visible only in a well defined AGN sample. The studies focused on three main areas: (1) obscuration and dust content, (2) X-ray radiation processes and spectra, and (3) dominant radiative components in the spectral energy distribution (SED) of radio-loud and radio-quiet AGN. The main research results are contained in the three sections of Gupta's thesis, each linked to the published refereed journal article. These publications have already been cited by other researchers, with a total of 24 citations today, underlying the importance and relevance of the presented research.

The introduction chapter of the thesis contains several sections with an overview of the research topic, motivation and results. It provides a broad description of AGN properties, highlights several classes of AGN and the division between radio-loud and radio-quiet sources. This chapter also contains a description of the standard AGN structure and the emission components contributing to the radio, IR, optical-UV and X-ray bands with a discussion of specific radiation processes in each band. The methodology section discusses different aspects of the performed analysis, data catalogs used in the research, source pair matching and selection process, methodology of black hole mass measurements, and the methods of calculating the bolometric luminosity. Overall, the introduction lays out the necessary background information and science overview of the results required to fully comprehend the topic of the research.

The AGN samples have been selected from publicly available source catalogs focusing on the selection criteria, which avoid any possible biases in each part of the studies. They cover both ends of the radio-loudness parameter with a representative number of radio-quiet and radio-loud sources at low redshift. The selection criteria focused on the specific range of accretion rates and luminosities, and black hole masses. This is the first study of such samples resulting in new and important data on the AGN properties. In addition, the new method of source selection and pair matching have been developed and applied in this research.

The main outcome of the studies is reviewed in the introduction and the details are provided in separate chapters and sections devoted to each published paper.

The first article, *"Covering factors of the dusty obscurers in radio-loud and radio-quiet quasars"* published in 2016, focuses on the outermost regions of an accretion flow and the boundary conditions potentially leading to the jet production in radio-loud sources. It relates the heating and reprocessing of high frequency radiation by dust to the observed dust covering fraction, but finds no difference in dust covering fraction between the two AGN classes, or any dependence of covering fraction on the Eddington ratio. The main conclusion is that the geometry of a torus is similar in radio-quiet and radio-loud sources and no significant differences are observed that could result in a jet.

The research published in the second article, *"Comparison of hard X-ray spectra of luminous radio galaxies and their radio quiet counterparts"*, focuses on studies of hard X-ray spectra that may indicate differences in the radiative properties between the AGN. The hard X-ray catalog, Swift/BAT used as a primary catalog for the source selection is the only currently available all-sky survey catalog in the 14-145 keV energy band, and very well suited for the studies. This is where the potential differences in radiation processes between the corona and jet might become detectable. The results confirmed a higher X-ray loudness parameter, i.e. excess in X-ray luminosity, in the radio-loud sources. However, there was no difference found in the X-ray spectral properties between the two AGN classes. The paper postulated that the hard X-ray radiation in both classes is associated with the hot, geometrically thick innermost regions of an accretion flow involving comptonization of the lower frequency radiation. In such a case the higher X-ray loudness might be explained by the faster black hole rotation in radio-loud than in radio-quiet AGN. This result is also interesting in terms of explaining less prominent signatures of the reflection in radio-loud quasars, which would be expected in the more centrally concentrated X-ray radiation regions in accretion flow onto a higher spinning black hole in radio-loud sources.

The final chapter of the thesis and the third publication, *"Comparison of SEDs of very massive radio-loud and radio-quiet AGN",* focuses on description of dominant radiation components present in the full spectral energy distribution (SED) in radio-loud and radio-quiet AGN. The sample is again selected from the Swift/BAT hard X-ray catalog, and targeting sources with known optical properties and large black hole masses. The results confirmed a higher X-ray loudness in radio-loud AGN and interestingly found that the average X-ray loudness is very similar in Type 1 and Type 2 AGN, where Type 2 are typically explained by being observed at the higher inclination angles. Thus the observed hard X-ray radiation does not depend on the inclination angle and the radiative output is dominated by mid-IR and hard X-rays in both populations. A large amount of polar dust leads to a weaker UV radiation.

Below I list a few questions regarding the topic of the thesis:

One of the conclusions presented in the first article was that the obscurer cannot be associated with the winds. This first article was published in 2016 before new results from ALMA showing detections of the fast molecular outflows in nearby galaxies were published. Does the conclusion still hold today?

The results of the first study do not show significant differences between the radio-loud and radio-quiet AGN in terms of dust covering factor. Could this be related to selection of FRII sources with radio emission dominated by the lobes and hot spots with relatively low radiation of the radio core?

What are the uncertainties on the black hole mass measurements using the template fitting described in the thesis and how they compare to the other methods generally used in AGN research?

The results of X-ray loudness presented in the second and third publications are very interesting showing the similar X-ray radiation processes present in radio-loud and radio-quiet AGN. Recent work by Zhu[1] et al. (2020) suggests that in the radio-loud AGN with their radio emission dominated by the radio lobes the X-ray radiation process in these sources is similar to the one in the radio-quiet AGN. On the other hand, the X-ray radiation in the radio core dominated radio-loud AGN is due to the jet. Could you provide your perspective and comment on Zhu et al. results in relation to your studies?

In summary, I consider the doctoral thesis of Maitrayee Gupta to be a valuable contribution to AGN research and to meet the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation be admitted to a public defense.

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[1] Reference:
Zhu, S.F., Brandt, W.N., Luo, B., et al. 2020, MNRAS, 496, 245. doi:10.1093/mnras/staa1411