Report on PhD thesis

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Title: *Variability and evolution of Active Galactic Nuclei*

This dissertation is a collection of three published articles (Chapters 2–4) accompanied with an informative introduction (Chapter 1), a short summary of the results and a brief presentation of forthcoming works (Chapter 5). The results included in the articles constitute a valuable contribution to the field of Active Galactic Nuclei (AGN), addressing the variability and evolution of active galaxies.

The theme of the dissertation centres around a "changing-look" (CL) phenomenon, including the most extreme case of this phenomenon in a form of "quasi-periodic eruptions" (QPEs), observed in a growing number of active galaxies. A particular attention has been paid to one of the possible scenarios of the origin of the regular or semiregular repeating outbursts intrinsic to the nucleus, based on the thermal instability driven by radiation pressure in accretion discs around supermassive black holes.

Finding the reason for the observed changes in the emitted fluxes and spectra of active galaxies will provide a breakthrough in the understanding of the structure and evolution of galaxies. Therefore, the problem considered in this PhD thesis is of a fundamental nature.

It is not only important to undertake such study, but also it is the right time to do so, taking into account a recent enormous progress in collecting high-quality data in the relevant bands of the electromagnetic spectrum. The availability of data makes the research presented in this PhD thesis timely and this aspect has been appropriately stressed in Chapter 1.

In Chapter 2 the idea of explaining the changes in CL AGN with the radiation pressure instability has been introduced. The idea itself in not new. For example, the time dependent studies of the accretion onto black holes using the slim disc model showed already in 1997–2001 that the thermal instability due to the radiation pressure could be a promising mechanism for modelling the observed changes in X-ray binaries and AGN. It is nice to see, though, that a toy model adopted in Chapter 2 has few features in common with the self-consistent time-dependent slim disc evolution around a black hole with the mass of 10^8 $M_\odot$ (Szuszkiewicz, 1999, MmSAI 70, 95). It should be stressed here that at that time the radiation pressure instability has been considered as an artifact of the assumptions made in the model and intensive calculations were

carried out in order to establish if this instability is realistic or not. Also, the convincing observational support for this process being operational in X-ray binaries and AGN was not substantial. Twenty years later, the consensus concerned with the physical nature of this instability is still not reached. Therefore, the interpretation of the observations is still done, using the standard parametrisations. This in fact, justifies the exploratory study presented in the dissertation performed in the framework of the radiation pressure driven instability in the accretion discs. However, it should have been clearly mentioned at least in Chapter 1 if not in the papers presented in Chapters 2 and 3.

In Chapter 3, the simple toy model from Chapter 2, with the single zone unstable region has been extended assuming the presence of the disc corona and radially resolved unstable cold disc. The calculation of the time evolution of this extended disc model around a black hole with the mass of 10^7 $M_{\odot}$ performed in Chapter 3 has not provided satisfactory explanation of the observed variability. Additional modifications of the model have been suggested, and further studies have been announced and briefly described in Chapter 5 (forthcoming works). The overall conclusion from this extensive exploratory study is rather pessimistic for the thermal instability due to the radiation pressure being operational in "changing-look" AGN and/or active galaxies showing "quasi-periodic eruptions". Even though, Pan et al. (2022, ApJ 928L, 18) claim that their disk instability model is capable to explain the quasi-periodic eruptions of GSN 069, low-mass Seyfert galaxy. The QPEs in this object have been found (Miniutti et al. 2022, arXiv220707511) consistent also with being produced by successive tidal stripping events of a white dwarf donor in a highly eccentric orbit around the supermassive black hole. In order to understand the actual nature of the QPEs, there must be a way to distinguish between those two and several other scenarios. Further studies are definitely needed. The exploration presented in this PhD thesis is helpful in choosing the most plausible directions for further investigations.

An attempt to find an additional argument in favour or against the variability scenario for "changing-look" or QPE active galaxies proposed in this PhD thesis is described in Chapter 4. The link of the results included in this chapter to the rest of the dissertation is based on the assumption that the highly accreting quasars correspond to the outburst states of a thermal instability cycle driven by radiation pressure. A detailed analysis of UV spectra of 13 highly accreting quasars performed by the author of this PhD thesis together with her collaborators allowed to estimate the chemical abundances of the broad-line-emitting gas in these objects. The results suggest very high metallicity values, significantly higher than those in lower accreting AGN. If confirmed (see Temple et al. 2021, MNRAS 505, 3247) this result can pose additional problem to the thermal instability scenario.

In my opinion, the most valuable contribution of the work presented in this dissertation is the author's thorough analysis of the apparently distant from each other observational facts and her attempt to indicate possible ways to put all facts in one self-consistent picture.

Interesting and significant results included in this PhD thesis could be better appreciated if the introduction was a little bit more focused on the "changing-look" and QPE phenomena, which by all means are the central types of variability considered in the PhD thesis. As it has been signalized in the text, the active galaxies showing those properties do not form a homogeneous class of objects. For this reason, it would have been helpful to discuss the relevant properties of these sources and justify the choice of objects to be modelled. The link between Chapter 2 and 3 is obvious, but the link to Chapter 3 should have been better presented. Moreover, the summary of the dissertation should have been more conclusive. The results briefly described at the end of the PhD thesis as the forthcoming works are important completion of the dissertation, however, after careful exploration of the possible interpretations of the observations, one could expect to find clear directions for further studies. The indication how to reach the final goal of understanding the "changing-look" events or QPEs has not been sufficiently pronounced.

Regardless of few shortcomings concerned with the presentation of the results, I consider the doctoral thesis of Marzena Śniegowska to be a valuable contribution 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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Szczecin, 2 August 2022

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