Report on the doctoral dissertation of Marzena Śniegowska: "Variability and Evolution of Active Galactic Nuclei"

The work presented by Marzena Śniegowska (hereafter simply Marzena) revolves around the study of Active Galactic Nuclei (AGN) variability on a variety of different timescales as well as on the chemical composition of gas in the immediate vicinity of highly accreting AGN at redshift z ~ 2.

The main subject of the first part of Marzena's dissertation is to investigate whether accretion disc instability models, that typically predict variability on very long timescales of hundreds/thousands of years, can be modified to be applied to Changing Look AGN (CL AGN), and Quasi-Periodic Eruptions (QPEs), where extreme variability is seen on timescales ranging from months to hours. The second part of the dissertation is instead devoted to the study of the chemical abundances in highly accreting AGN around the crucial redshift of z~2, via the detailed analysis of their rest-frame UV spectra obtained from the Sloan Digital Sky Survey (SDSS).

The first part of the thesis is therefore almost exclusively theoretical (involving detailed numerical simulations), while the second is purely observational. **Marzena has demonstrated to master both the theoretical/numerical and observational aspects in an excellent and mature way**, which is not very common especially at such an early stage of professional work. This broad range of abilities is very promising for her career as an astronomer/astrophysicist in the future.

Below, I provide a more detailed report on the dissertation:

- <u>Introduction (Chapter 1)</u>

  The introduction to the dissertation is very well written, and includes all key elements that are needed to set the stage for the subsequent presentation. Besides a relatively standard initial part on AGN structure and unification model(s), it introduces the fundamental aspects of AGN variability and of the CL AGN and QPE phenomena that are needed for a better understanding of the work presented in Chapters 2 and 3. The final part of the Introduction revolves around the key ideas associated with the determination of the Eddington ratio and metallicity in AGNs, as well as around the motivation for studying metallicities in highly accreting AGNs and the implications of any relation between the Eddington ratio and the gas metallicity for AGN evolution and metal enrichment (Chapter 4).

- <u>Modified disc instability models (Chapters 2 and 3)</u>

The work presented in Chapters 2 and 3 is based on the idea that the typical timescales associated with radiation pressure instability in supermassive black hole accretion discs can be significantly shortened if the unstable region is confined to a narrow ring between a standard outer disc and an inner advection-dominated accretion flow. Shortening the predicted outburst recurrence times from hundreds/thousands of years to timescales as short as days/months may then provide a viable explanation of the otherwise puzzling phenomena of CL AGN and, possibly, QPEs. Chapter 2 presents a toy model that explores the ideas outlined above, and its application to a few specific cases of highly variable sources. The model is well explained, and its current limitations are presented clearly together with possible paths for a way forward.

Chapter 3 represents a first extension of the toy model presented in Chapter 2 and makes use of radially-resolved 1D models (using the time-dependent GLADIS code) allowing to explore different scenarios for the mass exchange between the disc and the corona, as well as for the disc evaporation. The work points out the critical role of the outer disc radius for the shortening of the timescales associated with the radiation pressure instability, something worth exploring in the future with a code allowing for a dynamical outer disc edge. The analysis also shows that, while the instability mechanism may be viable for the CL AGN phenomenon, it is unlikely that the timescales associated with WPEs, as short as few hours, can be obtained. On the other hand, as QPE sources are most likely associated with Tidal Disruption Events (TDEs), and since one expects very compact accretion discs with evolving outer edges (due to viscous spreading) in this case, results from a code with dynamical outer disc radius are surely worth exploring. I would also like to suggest to consider, for TDE sources, the fast mass accretion rate evolution as well in the future, as it may have an overall impact on the unstable region size.

Marzena is first author of the two published works presented in Chapters 2 and 3 respectively. Her contribution in both articles is clearly dominant and can be estimated to be of the order of 80%.

- UV spectroscopy of highly accreting, z~2 AGNs (Chapter 4)

In Chapter 4, Marzena presents the results from her work based on the analysis of the rest-frame UV spectra a pilot sample of 10 quasars, selected from the SDSS data release 12 as members of the population of so-called xA quasars, namely sources representing the extreme tail of the highly-accreting quasar population. The data analysis is complete and detailed. Accurate diagnostic-lines ratios are obtained and they are then connected to relative chemical abundances by re-constructing the ionic stage distribution for each element via state-of-the-art simulations using the well-known CLOUDY code. Marzena utilizes a method to determine the metal content of the broad line region (BLR) that relies on ratios involving the He II λ1640 line, a procedure that was not given enough attention in past studies and that appears to be reliable and robust. The "standard" two-zones BLR are very well accounted for (the low-ionization, virialized one, and the high-ionization outflowing ones). A correlation between metallicity and outflow prominence is relatively well established from previous studies and, as the sources studies by Marzena show the highest blueshifts, one would expect to find particularly high metallicities in the sample. Indeed, Marzena shows that metallicities values for the sample are systematically in excess of 10 $Z_{\odot}$, a result that has important consequences for our understanding of AGN chemical evolution. Her results are also promising in terms of future developments as the methods used in her work can be applied to much larger samples in the future, allowing one to study the metal enrichment mechanism(s) on galactic scales.

Marzena is first author of the two published work presented in Chapter 4. Her contribution can be attributed to the detailed data analysis and modelling of the rest-frame UV spectra plus the comparison with photoionization models using the CLOUDY code. Her contribution can be estimated of the order of 70%.

Report's summary:

I consider the doctoral thesis of Marzena Śniegowska **to be an outstanding scientific contribution** to the field of Active Galactic Nuclei, and **to meet by far the criteria prescribed by the law for a doctoral dissertation**.

Therefore I request that this dissertation be admitted to a public defense.

In Madrid, 30 July 2022

(Giovanni Miniutti)