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Thesis report – M. Jakub Podgorny (Observatoire Astronomique de Strasbourg)
French title : « *Les propriétés de polarisation de l'émission X-ray des trous noirs supermassifs accrétants* »

Marseille, November 24, 2023,

The PhD thesis of M. Jakub Podgorny entitled "*Polarisation properties of X-ray emission from accreting supermassive black holes*" (defence date on December 12, 2023) is dedicated to the development of complementary numerical codes and routines to interpret X-ray polarimetry observations of matter surrounding not only supermassive black holes (here active galactic nuclei, AGN), but also stellar-mass black holes (here X-ray binaries, XRB). The understanding of black-hole accretion disc's formation, stability and radiation properties being one of the most challenging work of today's astrophysics. In particular, AGN are very complex astrophysical objects with many different spatial regions, which span from a few gravitational radius (disc-corona system) to more than the parsec scale (e.g. molecular torus), which cannot be studied independently since they interplay with each other through light path (emission, absorption, re-processing) and are not yet spatially resolved in X-rays.

Thanks to the recent launch of the Imaging X-ray Polarimetry Explorer (IXPE; NASA/ASI) in December 2021, X-ray polarimetry is now a new powerful window to probe the physical processes and geometry – in both independent and complementary manners to X-ray spectral, imaging and timing studies – of many astrophysical objects from Galactic to extragalactic astrophysical ones. Due to the novelty of this research field, though some previous X-ray polarimetry have been performed in the past in a handful of objects (but only one trustworthy detection in the Crab nebula), the development of new and performant numerical codes is crucial to robustly interpret X-ray spectro-polarimetry observations offered by the IXPE mission and forthcoming X-ray polarimeters. Such a very challenging task has been accomplished in an impressive way by Jakub thanks to his undoubtedly remarkable level of understanding about radiative transfer, general relativity, and physical processes in general. His dissertation is divided into 6 chapters and is written in an elegant and lively manner.

Chapter 1 is an introduction section offering a very informative and relevant overview about photon polarisation, X-ray polarimetry, AGN, XRB, and the computational approach performed during his PhD thesis. This chapter includes the necessary knowledge to fully apprehend all the richness of the outstanding work accomplished by Jakub during his PhD thesis both in quantity and quality, which is presented in the following four chapters. Chapters 2 and 3 are dedicated to characterise the polarisation features of matter in the very close environment of stellar-mass (XRB) and supermassive (AGN) black holes. Jakub built two local accretion disc emission models in plane-parallel approximation, either through reflection or transmission (Podgorny et al. 2022, 2023a). The first one is dedicated to the disc-corona system in AGN (work started during his master thesis) and the second one to XRB. Both models required to combine the results from two complementary state-of-the art existing models, TITAN and STOKES. TITAN allows for ionisation structure calculations, while STOKES is a 3D Monte Carlo code including polarisation effects. The latter one has been co-developed and is currently developed by Frédéric Marin who is the co-advisor of this PhD thesis. Then in chapter 3, relativistic effects are included into the previous models (neutral and ionised discs) using the KY codes and routines created by Michal Dovciak who is the other co-advisor of Jakub's thesis. Jakub developed a new routine called KYNSTOKES, which considered two different hot corona geometries: lamppost and extended (also called sandwich corona). Chapter 4 describes new models (xsstokes_torus and xsstokes_disc) developed for components located at much larger distance from the black holes, such as the molecular torus in AGN or more ionised outflows in funnel-like structures, originating from the outer accretion discs of XRB (Podgorny et al. 2023c). Three different geometries are investigated such as a wedge-shape torus, a true geometrical torus and a circular profile torus. Both type-1 and type-2 AGN are considered. Last but not least, in this chapter, a toy model of an entire AGN is considered combining disc-corona system and far-away spectro-polarimetric features (Podgorny et al. 2023d). Chapter 5 provides observational analysis for XRB and AGN and perspectives with the latest operating or planned X-ray polarimeters (e.g., eXTP). Jakub contributed to the core IXPE team analyses (data reduction, analysis, and interpretation), specially in the XRB team where he was PI of an observation of LMC X-1 (Podgorny et al. 2023e). The final chapter provides several very promising possible continuation of his work.

I would like to note that the four chapters related to his work are not simply a summary of his publications but are a global view of his works with existing updates. Therefore, this dissertation will undoubtedly be a reference document in this field. For all models and routines developed, Jakub performed a thorough investigation and check of the impact of the parameter space and assumptions of the models onto the resulting spectro-polarimetric features. He also discussed very honestly the current limitations and possible bias of the current models, which reflect an obvious scientific maturity. During all his work, he aimed to find the best trade-off between the physical approach of such very complex astrophysical objects and the practical approach to allow for efficient fitting of the data. Moreover, he compared his spectral results with other public codes when possible. All models and routines developed during his PhD thesis have been made publicly available and usable inside XSPEC, which is the most worldwide used X-ray fitting data code.

During his thesis, he led and participated in about a dozen of refereed publications including five accepted publications as first author and one currently in a referee process. Such very high publication efficiency is rare in only a three-year PhD thesis.

The results provided by his work are extremely promising and will be followed by many improvements as discussed by Jakub in his dissertation. Jakub, thanks to his high-level scientific skills and his hard work capabilities, has very significantly participated in paving a new way to study AGN and XRB, and more generally all high-energy cosmic sources. In summary, the scientific level of the PhD thesis of Jakub Podgorny is exceptional with excellent quality of the dissertation.

To conclude, the PhD thesis of Jabub Podgorny undeniably deserves to be defended in view for obtaining the grade of Doctor without modifications.

Signature
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