Obserwatorium Astronomiczne Uniwersytetu Warszawskiego

Prof. dr. hab. Łukasz Wyrzykowski
Astronomical Observatory
University of Warsaw
Al. Ujazdowskie 4
00-478 Warsaw
Poland

Warsaw, 2 December 2025

Review of the doctoral thesis of
Vikram Kumar Jaiswal
Center for Theoretical Physics, Polish Academy of Sciences
entitled:
Light echo studies in active galactic nuclei and their application for distance measurement
supervisor:
Prof. dr hab. Bożena Czerny

The PhD thesis of Mr. Vikram Kumar Jaiswal addresses the timely and scientifically important problem of understanding continuum reverberation lags in active galactic nuclei (AGN). In recent years, reverberation mapping has revealed lags that are systematically larger and more complex than predicted by the standard thin-disk model, raising questions about the geometry and physics of the central engine. The thesis investigates this problem by developing and testing models that include additional sources of reprocessing, by adding broad-line region (BLR) reprocessing and extending the corona model. These models were then applied to both simulated data and real observations of an AGN in NGC 5548. In this work, PhD candidate attempts to explain the origin of the anomalous lags, but also tests the feasibility of using AGN reverberation as a cosmological probe to be used in independent measurements of the Hubble constant.

The thesis is composed of the extended introduction, followed by the three publications, accepted or submitted for publication. In total, it is contained in 189 pages and is written in English.

The Introduction is structured into three major parts. It opens with an extensive overview of quasar structure and the broad range of theoretical models that have been developed to describe its central engine, providing a historical context of the studies. This is followed by a well-written and comprehensive explanation of reverberation mapping, supported by an impressive list of literature references, including both the most recent papers and the older, seminal works in the field. The discussion also traces the long-standing challenges in understanding the structure and morphology of the BLR, effectively situating the thesis within this broader scientific effort. The third component of the Introduction addresses the use of AGN as distance indicators and the possibility of estimating the Hubble constant. The Introduction is written and edited with care, although some minor improvements are possible: for example, “figure” should consistently be capitalised (e.g., p. 38), and Section 2.6 on X-ray reverberation would benefit from including an illustrative example light curve from the cited studies.

The next chapters include the three publications forming the core of the thesis, where the PhD Candidate was their first author. Each of the papers is preceded with a brief introduction, which helps in connecting the content of the paper with the overall topic of the thesis.

Chapter 4 contains the paper published in 2023 in A&A. The paper addresses the long-standing problem that continuum reverberation lags observed in many AGNs are significantly longer than expected from standard single-component thin-disk models. The Authors investigate whether an additional source of reprocessing coming from the BLR could contribute to the observed delays. The paper aims to check whether combining disk and BLR reprocessing can reproduce the enhanced lags seen in recent monitoring campaigns, without invoking unphysically large disk sizes.

To test this idea, the Authors present a proof-of-concept model that couples standard disk reprocessing with a BLR reprocessor, treated as an extended scattering medium. Using simulated X-ray light curves and convolving them with the combined response functions, they explore how various BLR geometries, weights, and timescales modify the wavelength-dependent continuum lags. This approach allows them to isolate the impact of BLR scattering on both the shape and amplitude of the lag-wavelength relation.

The study demonstrates that including BLR reprocessing can indeed produce significantly larger and more complex lags, consistent with what is measured in many AGN, and therefore offers a physically plausible explanation for the apparent discrepancy with disk-only theory. At the same time, the Authors identify a strong degeneracy: enhanced BLR scattering can mimic the effects of increasing the corona (lamp-post) height, making it difficult to distinguish between disk geometry and BLR contributions based on lags alone. They conclude that resolving this degeneracy and reliably interpreting continuum lags will require high-quality, well-sampled multi-wavelength light curves with broad spectral coverage.

The paper is presented in a clear and well-structured manner, with the motivation, methodology, and conclusions laid out logically and easy to follow. The figures, while somewhat small in places, remain readable and adequately illustrate the key results, supporting the main arguments of the study. Overall, the presentation quality is solid and allows the reader to understand both the technical approach and its implications without difficulty.

Chapter 5 includes Paper number 2 of the thesis composition. At the time of the review, it has been published in A&A (2025) and already has 3 citations, indicating the importance of the work in the community. It has also been led by the PhD candidate as the first Author. The work describes the application of the model determined in the first paper to an actual case of the Seyfert galaxy NGC 5548 and describes how it brings towards determining the Hubble constant.

The main motivation of the paper is similar to the Paper 1, i.e. the problem that the measured continuum time delays in many AGNs systematically exceed what is predicted by a simple standard accretion-disk model. The paper aims to build a physically motivated model that includes both disk and BLR reprocessing, apply it to a well-studied case of NGC 5548 active galaxy, and check whether it can simultaneously reproduce the observed broadband spectrum, the broad emission–line delay and the continuum lags.

The AGN emission was modelled with the following components: accretion disk, corona (with hot X-ray corona) and the BLR. Reprocessing of irradiating flux from corona / disk was computed for both the disk and the BLR. The BLR was modelled as a three-dimensional distribution of clouds (from FRADO) and the spectral-synthesis code CLOUDY code was used to estimate the diffuse continuum reprocessed by the BLR. The contribution from the host galaxy starlight was also included when modeling the observed spectrum. The three variants were considered (Models A, B and C), with different components included and different mixes between the main contributors.

The observational high-quality data for NGC 5548 was then modelled. They included a broadband spectral energy distribution and multi-wavelength continuum time delays from the intense monitoring of the so-called STORM campaign (HST + Swift + many ground-based observatories). The proposed model correctly predicted continuum inter-band delays, broad emission line delay and predicted spectrum.

One crucial idea implemented in the modelling was the inclusion of the luminosity distance as one of the model parameters. This in turn, allows to derive a value of the Hubble constant from a single AGN observations, effectively testing the feasibility of AGN-based cosmology via continuum reverberation mapping. This is a striking result, despite it was derived for just a single object, it represents a proof of concept that a carefully modelled AGN (disk + BLR) can yield meaningful cosmological constraints, if data quality is sufficient. The paper positions this as a first step toward using continuum reverberation mapping of AGN as a tool for cosmology.

Despite its potential breakthrough nature, there are some limitations to this approach which were not adequately addressed in the paper. First, although the FRADO+BLR modelling is physically appealing, the number of free parameters in the full model is large compared to the amount of independent observational constraints. This makes the solution space potentially degenerate, and it is not always clear whether the preferred model is uniquely determined or it is simply one of many acceptable fits. Moreover, the BLR geometry and its physical properties are assumed to follow a specific BLR model (FRADO) what predetermines the form of the response function, which may bias the inferred contributions to the lags. Additionally, hence there was only one case of an AGN studied, the work serves more as a proof of concept than a mature, widely applicable technique, and further validation across a larger AGN sample will be necessary before the approach can be considered robust.

The chapter is supplemented with two appendices which were not included in the originally published work, which present in more detail the results of the fitting procedures to the data as well as the computation of the effect of the shielding effect in BLR.

Fig.10 and Fig. 11 seem to shows the very same thing in their upper panels, basing on their captions, however, the plots look different.

Chapter 6 (Paper 3) tests a model of the AGN corona using reverberation mapping. The work focuses on the question if the UV/optical time-domain observations and reverberation mapping can be affected if the corona was considered to be vertically extended (two lamp-posts) instead of being point-like composed of a single lamp-post.

Using this two-lamppost geometry, the expected response of the disk is computed following a short X-ray impulse, and from that the wavelength-dependent delays for UV/optical emission are derived. The standard single lamp-post quantities are derived for comparison. Then, the light curves are simulated for the two geometries and sampled at a cadence typical for reverberation campaigns. The lags are measured by computing the cross-correlation functions.

In the conclusion, it was found that there is little or no difference between the two models, even when a very high cadence sampling is applied. Therefore, the authors argue that corona geometry alone is unlikely to explain the large observed lags.

There are couple of typos and minor editing mistakes in the paper, however, I assume they will be addressed at the proof-reading stage after the paper is accepted for publication.

SUMMARY

Summarising, I think the PhD candidate has done an enormous research work and has done it very carefully and laboriously. The thesis contains a wealth of studies on the topic and yields important novel discoveries. The Author demonstrated his proficiency in research through the completion of numerous complex tasks in data handling, astrophysical analysis, modelling, and interpretation throughout the thesis.

In my view, Mr. Vikram Kuma Jaiswal's work meets all the necessary requirements imposed on PhD theses in Poland, and I, therefore, recommend it for further consideration.

Łukasz Wyrzykowski

Warsaw, 2 December 2025

prof. dr. hab. Łukasz Wyrzykowski

Center for Theoretical Physics
Polish Academy of Sciences
Aleja Lotników 32/46, 02-668 Warsaw
Tel. (+48 22) 847 09 20, Fax/Tel: (+48 22) 843 13 69
E-mail: cft@cft.edu.pl, NIP: 525-000-92-81, REGON: 000844815

Konkluzja recenzji rozprawy doktorskiej
(Conclusion of dissertation review)

„LIGHT ECHO STUDIES IN ACTIVE GALACTIC NUCLEI AND THEIR APPLICATION FOR DISTANCE MEASUREMENT"

Tytuł rozprawy *(Dissertation title)*: ………

Vikram Kumar Jaiswal

Autor rozprawy *(Author of the dissertation)*: ……………………………………………………………………………………………

X

Pozytywna ocena *(Positive conclusion)*:

Stwierdzam, że przedstawiona mi do recenzji rozprawa spełnia wszystkie wymagania ustawowe i zwyczajowe stawiane rozprawom doktorskim i wnoszę o dopuszczenie jej do dalszych etapów postępowania doktorskiego, uwzględniając publiczną obronę.

*(I conclude that the presented dissertation meets the formal and customary requirements for doctoral dissertations and I recommend its admission to subsequent stages of the procedure, including the public defense.)**

Ocena negatywna *(negative conclusion):*

Stwierdzam, że przedstawiona mi do recenzji rozprawa nie spełnia wszystkich wymagań ustawowych i zwyczajowych stawianych rozprawom doktorskim i dlatego nie rekomenduję dopuszczenia jej do dalszych etapów postępowania doktorskiego.

*(I conclude that the presented dissertation does not meet the formal and customary requirements for doctoral dissertations and therefore I do not recommend its admission to subsequent stages of the doctoral procedure.)**

Uzasadnienie powyższej oceny znajduje się w raporcie będącym załącznikiem 1.
(The justification of the above assessment can be found in the detailed report in the attachment 1.)

2/12/2025 Z. Wyszkowski ……………………………
Data i podpis
(Date and signature)

Załącznik 1: Recenzja rozprawy doktorskiej
(Attachment 1: Review of the dissertation)

**Zaznacz ocenę (Please tick the box with your conclusion)*