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Annex No. 10 to the MU Directive on Habilitation Procedures and Professor Appointment Procedures

HABILITATION THESIS REVIEWER'S REPORT

Masaryk University	
Applicant	RNDr. Michal Zajaček, Dr. rer. nat.
Habilitation thesis	Mapping galactic nuclei: From the Galactic center to distant quasars and back
Reviewer	Prof. Iossif Papadakis
Reviewer's home unit, institution	Physics Department, University of Crete, Greece https://www.physics.uoc.gr/en/faculty/i.papadakis

It is with a great pleasure that I write this review for Dr. Zajacek's Habilitation thesis.

I state from the start that I am not familiar with the procedure of "Habilitation". This procedure is not in place neither in Greece, where I work, nor in the UK where I did my PhD studies. I understand that the award of Habilitation guarantees that the candidate fulfills certain criteria of excellence in research and teaching. I also understand that the award of Habilitation is αλσο a qualification for a full professorship for the candidate. Before continuing with my report on the Habilitation thesis, I would like to clearly state that, if it were for Greece, or other countries across Europe where the Habilitation procedure is not practised, the academic qualifications of Dr. Zajacek are of the highest quality and are more than enough to guarantee him a permanent position in any University across Europe.

I do not have access to his full CV, however, based on the number of published papers and the number of citations to his published work, I would confidently state that Dr. Zajacek is a highly productive and widely recognised (globally) young Astronomer in the field of Theoretical High Energy Astrophysics. The high quality of his work is not based just on these numbers, however. I have had the opportunity to hear Dr. Zajacek present oral talks in various conferences, and I have appreciated his intellect, his deep and broad knowledge of both his specific research work and Astrophysics in general. I greatly value his ability to choose problems of high importance to work with, and I fully admire his ability to produce excellent and very important results, with significant implications to various areas in High Energy Astrophysics.

I would like to highlight his work on the electric charge of black holes. This is a brilliant example of a scientist who explores (successfully) research areas that other scientists may take for granted. Overall, I truly believe that Dr. Zaječek is at a stage in his career comparable to other bright, young Astronomers who are in tenure track positions in a University and are about to achieve tenure. I firmly believe that Dr. Zaječek would greatly deserve such a tenure position, in any Physics Department, worldwide.

I apologize for the lengthy "Introduction" in my report, but I wanted to make sure that I express correctly and clearly the highest opinion that I have for Dr. Zajacek as a scientist. And to do so, I decided to write the text above, which could be a short resume of the evaluation report that I would have written for Dr. Zajacek, if he were a candidate for an Associate Professorship position in my Institution.

Dr Zajacek's Habilitation thesis is comprised of a lengthy and comprehensive review on the Galactic Center and on Active Galactic Nuclei (AGN). The Introduction reports the State of Art in these research areas. In the first part of the Introduction, he presents our current knowledge on the stellar populations and on the distribution of gas in the vicinity of Sag A*, i.e. around the supermassive black hole (BH) at the center of our Galaxy.

He also describes in detail the nature of the accretion flow in the central black hole of our Galaxy. In the second part of the Introduction, Dr. Zajacek explains in detail our current knowledge on the various accretion processes that operate at the center of AGN (depending on the accretion rate of these objects). He explains the method of reverberation mapping and its important role in our understudying of the inner structure and geometry of the accretion disc, the X-ray source as well as the broad line region (BLR) clouds in AGN. He discuses the important BLR radius-luminosity relations, the UV-X-ray luminosity relation, the recent results on tidal disruption events and the so called quasi-periodic eruptions that have been detected very recently in the X-ray emission of a few AGN. The Introduction is very well written and it is very well organised. It presents all the important results in the field of AGN research, both for the nearby and the distant objects, and clearly demonstrates the deep and broad knowledge that Dr. Zajacek possesses in the field.

In addition to the Introduction, the Habilitation thesis consists of seven chapters where Dr. Zajacek presents the results from pairs that were published the last six years. Five of these papers deal with AGN in distant galaxies, while two other two papers focus on the Galactic center. The topics of the papers are quite broad. They are related with the study of physical properties of the nuclei at the center of the active galaxies, and they representative of the wide range of the research topics that Dr Zajacek work on.

I find the work presented in Chapters 3 and 5 particularly interesting and important. The broad emission lines in AGN are variable, and their variations are very well correlated with the variations of the photoionizing continuum which drives their variations. A tight relation between the BLR radius and the continuum luminosity has been established for the broad H-beta emission line in nearby AGN. The radius of the BLR is computed by studying the time-delay between the continuum and the H-beta line variations. The BLR radius-luminosity relation is important not only because it can help us understand the geometry of the BLR in these objects, but also because it can be used too estimate the BH mass in AGN using just a single observed energy spectrum. By measuring the continuum luminosity we can use the BLR radius - luminosity relation to estimate the radius of the BLR and, together with the measurement of the width of the same emission line (as is detected in the optical spectrum) we can also estimate the mass of the BH. However, as the redshift of an AGN increases, H-beta is redshifted out of the optical spectra, while the shorter wavelength Mg II line is now redshifted to the visible portion of the spectrum. Chapters 3 and 5 describe the work that Dr. Zajacek did in order to: a) measure the BLR radius by studying the delays between the Mg II line and the continuum variations in distant quasars, b) establish that there is also a BLR radius-luminosity relation even for the Mg II emission line and c) determine the best-fit parameters for this relation. His work was the first to accurately determine the BLR radius - luminosity relation based on the Mg II line measurements, and his results have important implications. Using the BLR radius - luminosity relation that he established, we can now compute BH masses for higher redshift quasars. Consequently, we can study the growth of the BH mass at the center of galaxies as a function of redshift and in particular at the period close to the peak of the BH accretion and start formation rate. This have important implications for cosmological models regarding the BH growth across cosmic time and galaxy evolution models.

Furthermore, the BLR radius - luminosity relation has significant cosmological implications as well. Once the BLR radius of an AGN is known, then its luminosity can be determined, hence its luminosity distance as well. Therefore, one can use quasars in order to study the luminosity - redshift relation at high redshifts and test current cosmological models. Dr. Zajacek already used the BLR radius - luminosity relation and determined the luminosity of 27 high-accreting quasars (in the work described in Chapter 5). Then he fitted the resulting luminosity-redshift relation for these objects assuming a general ΛCDM model, and he derived Omega matter and Omega Lambda values which are in full agreement with the values which are based on the study of the CMB anisotropies.

The work presented in the 7th Chapter is closely related with the work presented in Chapters 3 and 5. A positive, non-linear relation between the luminosity of AGN in the far UV (2500 Angstroms) and in X-rays (at 2 keV) has long been established in AGN. If this relation does

not depend on redshift, then it can be used to establish a luminosity - redshift relation using quasars, even at high redshifts. Results from such analysis in the past indicated a strong tension between the standard ΛCDM model (as determined from the Planck data) and the quasar based cosmological parameters. In his recent work, Dr. Zajacek used a clever and highly original method to test the significance of the tension between the cosmological parameters derived from the study of the L_X vs L_UV relation of quasars and the standard ΛCDM cosmology. He considered a sample of 58 quasars where the luminosity could be established both from the “BLR radius - luminosity” and the “L_X vs L_UV" relations. He showed that the respective luminosity distances were not in agreement within their respective errors. This result alone was very important but actually Dr. Zajacek went a step ahead and he explained the reason for this disagreement. He showed, very convincingly, that the main reason for this disagreement is extinction in the optical/UV part of the spectrum due to the presence of dust in the host galaxy of the quasars. This effect should affect the quasar luminosities derived from the L_X vs L_UV relations. The amount of extinction necessary to explain the disagreement between the various luminosity measurements is entirely reasonable, hence his work was able to demonstrate the reason behind the apparent discrepancy between the cosmological parameters based on quasars and those of the standard model of Cosmology.

I presented a short overview of these three works that Dr. Zajacek presented in his Habilitation thesis, mainly because they align closely with my own research topics, hence I can better understand their significance. Moreover, I believe these works clearly demonstrate the impressive capabilities of Dr. Zajacek in conducting significant and highly original research across various fields. Up to 2019 Dr. Zajacek was mainly studying our Galactic center, with notable success. Later, he started studying statistical methods for the estimation of the cross-correlation functions between the continuum and the line variations in AGN, the BLR line - luminosity relations for large sample of quasars and their cosmological implications. Although Dr. Zajacek rightly asserts that all the works in his thesis share a common theme - i.e “astrophysics of (active) galactic nuclei” - it takes considerable stamina, an in-depth knowledge of astrophysics and statistical methods of data analysis, and exceptional ability to simultaneously work, successfully, on such a broad area of very demanding subjects. While all the topics are related to the same, fundamental theme, each one demands expertise in different analysis tools and deep knowledge of the underlying theory to make substantial progress in a short period of time.

I read with great interest the other chapters in Dr. Zajacek’s thesis as well, and this study only reinforced the high opinion that I have of Dr. Zajacek’s work. I believe he is a highly successful young Astronomer, capable of producing high quality, and very successful work in the future.

I am not certain whether I should also comment on Dr. Zajacek’s comment on his teaching ability. I have heard him several times giving oral talks in conferences, and I can confidently attest to his skills as a speaker. He is articulate and he can explain difficult and complex issues in a clear and didactic manner. He is very motivated and pleasant, and his talks can certainly keep the audience’s attention at all times. Arguably, it is not always true that an excellent speaker in scientific conferences will also be a good teacher, but I have the feeling that Dr. Zajacek will also be a good teacher with his student at the University.

Conclusion

The habilitation thesis entitled “Mapping galactic nuclei: From the Galactic center to distant quasars and back” by Dr. Michal Zaječek **fulfils t**he requirements expected of a habilitation thesis in the field of Theoretical Physics and Astrophysics.

Date: 12/5/2025

Signature: Iosif Papadakis

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