Supervisor's assessment of the dissertation

Author of the thesis:	RNDr. Marcel Lamač
Title of the thesis:	Relativistic Optics: The Frontier of Ultrashort X-ray Pulse Generation
Faculty, University:	Faculty of Mathematics and Physics, Charles University
Year:	2024
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The doctoral thesis entitled "Relativistic Optics: The Frontier of Ultrashort X-ray Pulse Generation" by Marcel Lamač explores the cutting-edge field focusing on the interaction between ultra-high-intensity laser pulses and plasma. This area of research is motivated by the advances in high-power laser systems that enable such interaction. The creation of relativistic mirrors, which can blueshift and contract radiation pulses due to the relativistic Doppler effect is a typical example of a groundbreaking application of this field. The thesis provides a comprehensive overview of the theoretical foundations, including laser-plasma interaction in underdense and overdense regime, and generation of radiation by relativistic particles.
Besides a very thorough theoretical basis presented in the thesis, the original results of the dissertation materialized in four attached publications based on numerical simulations and detailed theoretical analyses.

1. **Anomalous Relativistic Emission from Self-Modulated Plasma Mirrors:** Published in *Physical Review Letters* journal, this work revealed that under specific conditions, the interaction of high-intensity laser pulses with plasma can lead to unexpected extreme ultraviolet radiation patterns, which are explained by the laser-driven oscillations of relativistic electron nanobunches that originate from a plasma surface instability.

2. **Bright Coherent Attosecond X-ray Pulses from Beam-Driven Relativistic Mirrors:** This paper, that has been submitted and is now available as a preprint on arXiv, investigates the generation of coherent attosecond X-ray pulses using laser-driven or beam-driven relativistic mirrors in underdense plasmas. The research introduces a mechanism where a plasma wave with amplitudes close to wavebreaking can act as a relativistic flying mirror, compressing and blue-shifting the counter-colliding laser pulse to produce bright X-rays with attosecond pulse duration. The results provide valuable insights into developing new light sources for ultrafast X-ray imaging and spectroscopy competing with the state-of-the-art multi-billion-euro free electron laser facilities.

3. **Two-Color Nonlinear Resonances in Betatron Oscillations of Laser-Accelerated Relativistic Electrons:** Published in *Physical Review Research* journal, this paper explores the nonlinear resonances in betatron oscillations induced by two-color laser fields. The research demonstrates that by using a combination of different laser wavelengths, it is possible to enhance the X-ray betatron radiation emitted by relativistic electrons. This finding is significant for optimizing the efficiency of X-ray sources based on laser-plasma accelerators.

4. **Generation of Intense Magnetic Wakes by Relativistic Laser Pulses in Plasma:** Published in journal *Scientific Reports*, this work examines the generation of intense magnetic fields through the interaction of relativistic laser pulses with plasma. The study provides evidence for the

formation of magnetic wakes through numerical simulations, which have important implications for laboratory astrophysics and the study of magnetized plasma environments.

During his doctoral studies, Marcel Lamač has demonstrated exceptional qualities as a PhD student. One of the most remarkable aspects of his work is his in-depth theoretical foundation that he was able to apply throughout all his projects. This rigorous theoretical groundwork not only provided a solid basis for his original research but also serves as a valuable resource for others entering this field. His intellectual curiosity has driven him to delve deeply into the nuances of laser-plasma interactions and other related phenomena, resulting in significant contributions to the field. Throughout his doctoral studies, he has shown remarkable independence in developing and executing his research projects. His self-motivation and dedication to his research have been exemplary, consistently leading to high-quality results and publications in highly impacted scientific journals. These qualities will undoubtedly serve him well in his future scientific career.
I am convinced that the amount of work reflected in the submitted dissertation fulfils and, in many aspects, exceeds the expectations of the doctoral program. That is why, from my position as the thesis supervisor, I can only recommend that the submitted dissertation be admitted for defense. Furthermore, subject to a successful defense, I recommend awarding the Ph.D. title to the author.

In Dolní Břežany, 30. 8. 2024

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Jaroslav Nejdl