Relativistic Optics: The Frontier of Ultrashort X-ray Pulse Generation

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In his 1905 work on the theory of special relativity, A. Einstein predicted that a radiation pulse reflected from a counter-propagating relativistic mirror undergoes blueshift and length contraction due to the relativistic Doppler effect. Nowadays, high-powered laser systems enable the creation of such relativistic mirrors through nonlinear processes that occur when a relativistically intense laser pulse interacts with plasma. The proliferation of high-powered laser systems in the past years motivates us to explore a new kind of nonlinear optics, which emerge due to laser-induced nonlinear oscillations of charged particles, the velocity of which can get close to the speed of light. The insights into what is now called relativistic optics have a transformative potential to advance particle acceleration, coherent X-ray pulse generation, laboratory astrophysics, ultrafast X-ray spectroscopy, medical imaging or radiotherapy, and many other applications. This doctoral thesis serves as a brief introduction to the field of relativistic optics, as well as a summary of the research conducted by the author in this field.