LABORATOIRE INTERACTIONS, DYNAMIQUES ET LASERS

LIDYL-ERL 9000
CEA, CNRS, Université Paris-Saclay

THESE LIDYL

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Le Vendredi 21 Février à 16H00

Maison de la Simulation, CEA Saclay

"Massively parallel algorithms for realistic PIC simulations of ultra-high intensity laser-plasma interaction, application to attosecond pulses separation of Doppler harmonics"

The modeling of the complex and highly non-linear mechanisms involved in ultra-high intensity (UHI) laser-plasma interaction requires the use of very challenging Particle-In-Cell (PIC) simulations in terms of numerical accuracy and computational cost. Until very recently, the most popular formulation of the PIC algorithm used finite-difference Maxwell solvers to advance Maxwell's equations in time and space as this allows very good parallelization up to millions of CPU cores. Unfortunately, such solvers can induce important numerical errors (e.g. numerical dispersion of electromagnetic waves in vacuum) or noise that can be highly detrimental to the modeling of UHI physics. The mitigation of these errors involves the use of very high spatio-temporal resolutions, which have prevented doing realistic 3D simulations of laser-plasma interactions at ultra-high intensities. To break this barrier, FFT-based high-order pseudo-spectral Maxwell solvers that are dispersion-free and accurate to machine precision are good candidates to replace finite-difference solvers in PIC codes. These solvers are however very difficult to scale up to millions of cores, as required by the most challenging 3D simulations. Indeed, global parallelization methods for pseudo-spectral solvers are only scalable to few tens of thousands of cores, or induce an important memory footprint, which also hinders the scaling of the method at large scales. In this thesis, we developed a novel, arbitrarily scalable, parallelization strategy for pseudo-spectral Maxwell's equations solvers. This method proved to be more scalable than previously proposed approaches, while ensuring a significant drop in the total memory use.

By capitalizing on this computational work, we conducted an extensive numerical and theoretical study in the field of Doppler high order harmonic generation on relativistic plasma mirrors, which can be produced by focusing of a high-power laser on an initially-solid target. In particular, we investigated feasible ways for producing isolated attosecond light pulses from these Doppler harmonics, with the so-called attosecond lighthouse effect. This effect relies introducing a wavefront rotation on the driving laser pulse in order to send attosecond pulses emitted during different laser optical cycles at different angles and filtering-out one of this pulse spatially in the far field. The attosecond lighthouse effect requires low harmonic beam divergences to be able to angularly separate attosecond pulses in the far field. Unfortunately, in the relativistic regime, the plasma mirror is curved by the laser radiation pressure and acts as a focusing optics increasing the divergences of harmonic beams and preventing angular-separation of attosecond pulses with the lighthouse effect. In this context, we developed two novel techniques to control and reduce the Doppler harmonic beam divergences. These techniques are based on tailoring the laser pulse phase or amplitude profiles in order to significantly inhibit the plasma mirror focusing effect and allow for a clear separation of attosecond light pulses. Furthermore, we developed an analytical model to predict the optimal interaction conditions that maximize attosecond pulses angular separation. Finally, we show that under realistic laser and plasma conditions, it is possible to produce isolated attosecond pulses from Doppler harmonics with the current generation of PetaWatt (PW) lasers.

Formalités d'entrée :

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