Efficient many-body modeling of wave-particle interaction in a periodic structure

Damien Minenna[4,3,2,1], Yves Elskens*[1], Frédéric André[3], Alexandre Poyé[1], Fabrice Doveil[1], Meirielen Caetano De Sousa[6,5], and Khalil Aliane[6,3,2]

[4]DAM Île-de-France (DAM/DIF) – Commissariat à l'énergie atomique et aux énergies alternatives : DAM/DIF – CEA Bruyères-le-Châtel 91297 Arpajon cedex, France

[3]Thales AVS – Thales (France) – France

[2]Centre National d'Études Spatiales (CNES) – Centre National d'Etudes Spatiales - CNES (Toulouse, France) – 18 avenue Edouard Belin 31401 Toulouse, France

[1]Physique des interactions ioniques et moléculaires (PIIM) – Centre National de la Recherche Scientifique - CNRS : UMR7345, Aix Marseille Université : UMR7345 – France

[6]Physique des interactions ioniques et moléculaires (PIIM) – Centre National de la Recherche Scientifique - CNRS : UMR7345, Aix Marseille Université : UMR7345 – France

[5]University of São Paulo (USP) – Rua do Matão 1372, CEP 05508-090, Cidade Universitária, São Paulo, Brazil, Brazil

Abstract

We investigate the nonlinear wave-particle interaction using a many-body (finite-N) description. In optics and plasma physics, this description has long been deemed impractical to model whole experiments due to its excessive number of degrees of freedom. To bypass this difficulty, we developed a reduced model validated for periodical structures, such as traveling-wave tubes, gyrotrons, free-electron lasers,of particle accelerators.
This approach is combined with a self-consistent hamiltonian in one space dimension to model the momentum exchange between fields and particles. From it, we build a symplectic integrator in time domain in order to reproduce wave coupling, field distortions, turbulence and chaos from the nonlinear dynamics of particles. Our numerical tool is validated against measurements from several industrial (15cm long) traveling-wave tubes with various geometries. Thanks to the drastic reduction of degrees of freedom, simulations are 200 to 500 times faster than alternative particle-in-cell codes for the same accuracy.

This enables us to investigate microseconds long effects (telecom signals, chaos) while the particle dynamics require picoseconds timesteps. Besides current industrial applications, we also adapt the model to the 4m long traveling-wave tube used at PIIM laboratory, Aix-Marseille University-CNRS, with which Landau damping and hamiltonian chaos have been observed.

1. D. F. G. Minenna et al., Europhys. Lett. 122, 44002 (2018).

2. D. F. G. Minenna et al., IEEE Trans. El. Dev. 66, 4042-4047 (2019).

*Speaker

Keywords: Wave particle interaction, Time domain numerical model