Advances in the understanding of ultrarelativistic beam-plasma instabilities

Laurent Gremillet[1,2,†], Virginia Bresci[3], Sébastien Corde[4], Xavier Davoine[1,2], Jérémy Faure[1,2,3], Martin Lemoine[3], Archana Sampath[5], Pablo San Miguel Claveria[4], Matteo Tamburini[5]

[1] *CEA, DAM, DIF, F-91297 Arpajon, France*

[2] *Université Paris-Saclay, CEA, LMCE, 91680 Bruyères-le-Châtel*

[3] *Institut d'Astrophysique de Paris, CNRS-Sorbonne Université, 98 bis boulevard Arago, F-75014 Paris, France*

[4] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, 91762 Palaiseau, France*

[5] *Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany*

[†] laurent.gremillet@cea.fr

Relativistic beam-plasma instabilities are ubiquitous in high-energy astrophysics where they are thought to dissipate into heat or radiation the kinetic energy of relativistic outflows from powerful sources [1]. This occurs through the generation of intense electromagnetic fluctuations that can scatter and decelerate particles to the point of forming collisionless shocks waves or triggering bright synchrotron-type emissions. Two main instability classes are known to prevail in relativistic beam-plasma systems: the essentially electrostatic, oblique two-stream modes (OTSI) and the essentially magnetic, transverse current filamentation (CFI) modes [2]. These instabilities also operate, usually detrimentally, in laboratory schemes involving the interpenetration of relativistic electron streams and plasmas, as in plasma wakefield accelerators [3] or ultraintense laser-solid interactions [4].

This talk will cover a series of recent theoretical and numerical results on relativistic beam-plasma instabilities. Most of this work has been conducted within the E 305 project at the SLAC/FACET-II accelerator [5], which aims to probe the beam-plasma instabilities excited by an ultrarelativistic (10 GeV), high-density ($\sim 10^{19-20}\,\mathrm{cm}^{-3}$) electron beam through various gas or solid materials. First, I will report on a spatiotemporal theory, validated by particle-in-cell (PIC) simulations, describing the growth of the OTSI in collisionless plasmas permeated by finite-length beams [6]. Second, I will present a simulation study of the propagation of the FACET-II beam in a solid-density target, revealing how the hierarchy between the OTSI and CFI depends on the target collisionality and the beam density. The PIC results will be interpreted in light of a general kinetic linear theory of the OTSI and CFI modes in the presence of collisional background electrons. Finally, with a view to better understanding the physics of the precursor of relativistic collisionless shocks, I will discuss recent simulation findings on the saturation mechanisms of the CFI arising in asymmetric plasma flows [7].

References

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