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Hybrid Vlasov-Maxwell simulations of phase mixing as a mechanism to produce kinetic Alfvén waves

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In the range of proton kinetic scales and even down to typical electron kinetic scales, many solar-wind observational analyses, theoretical works and numerical simulations suggest that the so-called kinetic Alfvén waves (KAWs) can play an important role in the mechanisms of turbulent energy dissipation and heating. Mathematically, KAWs are a wave solution of the two-fluid dispersion relation, in propagation quasi-perpendicular to a background magnetic field. They can be considered as the continuation of the magnetohydrodynamic (MHD) Alfvén mode at scales comparable to the ion skin depth, and/or the ion Larmour radius. Recently, kinetic numerical simulations of these kind of waves in solar-wind environment conditions suggested that resonant protons can be trapped by a pseudo-potential (Vásconez et al., 2014), resembling the process of particle trapping in an electrostatic potential well. This nonlinear resonant interaction produces significant deformations of the proton velocity distributions, through the generation of flat-top profiles, frequently recovered in spacecraft measurements.

Considering their high characteristic angles of propagation, KAWs have been invoked to explain the excess of perpendicular energy in observational data of the solar-wind magnetic field. So far, the physical mechanisms responsible for the production of the KAWs are still on debate. Phase-mixing is a mechanism that creates small scale Alfvén fluctuations in a direction transverse to a background magnetic field. When an Alfvén wave propagates in a region where an Alfvén speed shear is present, the wave experiences phase-mixing and small scale Alfvén fluctuations are produced in the direction perpendicular to the background magnetic field. This phenomenon was first studied by Heyvaerts and Priests, in 1982, in the MHD framework. These authors pointed out that phase-mixing is the most efficient mechanism to ensure the dissipation of shear Alfvén waves.

Since phase-mixing can generate quasi-perpendicular Alfvén fluctuations, in this work we investigate whether it can triggers KAWs excitation. To this purpose, we need to study this physical process in a range of scale that goes at least from the smallest scales of MHD to a fraction of the ion skin depth, in linear and nonlinear regimes of wave propagation. To resolve the kinetic scales, we use the low noise hybrid Vlasov-Maxwell (HVM) code (Valentini et al., 2007) and an Hall-MHD code to control the smallest MHD scales. For the linear regime, we present some physical properties of the perturbations produced after the Alfvén speed shear, which are in good agreement with those discussed by, e.g., Vásconez et al., in 2014 (and references therein).

Then, moving to the nonlinear regime, the comparison of the results of Hall-MHD and HVM simulations allow to point out the kinetic effects at play during the phase mixing process.