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Resonant Decay of Kinetic Alfvén Waves and Implication on Spectral Cascading

Kexun Shen[1], Zhiwen Cheng[1], Zhiyong Qiu[2,3]
[1] Institute for Fusion Theory and Simulation, School of Physics, Zhejiang University, Hangzhou 310027, People's Republic of China
[2] Key Laboratory for Frontier Physics in Controlled Nuclear Fusion and Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, People's Republic of China
[3] Center for Nonlinear Plasma Science and C.R. ENEA Frascati, C.P. 65,00044 Frascati, Italy
e-mail (speaker): kxshen10@zju.edu.cn

Shear Alfvén waves (SAWs) are incompressible electromagnetic fluctuations ubiquitous in space, astrophysical and laboratory systems as miscellaneous as the solar wind, the magnetosphere, the interstellar medium, and fusion devices. Small-scale kinetic Alfvén waves (KAWs) uniquely characterized by a finite parallel electric field component and the perpendicular propagation across the mean magnetic field are often found to be generated from SAWs via linear mode-conversion due to intrinsic plasma nonuniformities or nonlinear wave-wave interactions. Since magnetized plasma turbulence is often characterized by low-frequency fluctuations and strong anisotropy in correlation length with respect to the mean magnetic field, it is of crucial point to quantitatively determine the complex Alfvénic nonlinear dynamics. Previous studies on weak-turbulence mode-mode coupling processes of SAW/KAW have focused on the parametric decay into ion acoustic waves and/or ion-induced scattering[1], where qualitative difference between ideal-MHD results and kinetic results are addressed, which demonstrate the crucial importance of kinetic description in the study of KAW nonlinear processes.

In this work[2], using nonlinear gyrokinetic theory, the general nonlinear equation describing three-wave interactions among KAWs in uniform low-β plasmas is derived, and as a first application, we mainly study the parametric decay of a pump KAW into two sideband KAWs with emphasis on the cascading behaviors in the perpendicular wave-number space underlying the spontaneous decay condition as shown in Fig. (1). It is found both analytically and numerically that, for the "co-propagating" cases with all three KAWs propagating in the same direction along the equilibrium magnetic field-line, it exhibits a dual-cascading character in the perpendicular wave-number space, similar to that of drift wave (DW) cascading described by the well-known Charney-Hasegawa-Mima equation[3]; while for the "counter-propagating" cases with one sideband propagating in the opposite direction with respect to the pump wave, it instead, can exhibit both dual- and inverse-cascading behaviors, and inverse-cascading has a larger nonlinear cross-section in the long-wavelength region.

The general nonlinear equation will be further used to study the self-consistent turbulent evolution and saturated energy spectra of KAWs with physical drive and dissipation terms. The conservation laws, quadratic invariants, Kolmogorov's weak/strong turbulence exponents, vortical structures, and thermodynamics of KAW turbulence will be given in future works with comparison to direct numerical simulations. The present theoretical framework would shed light on the turbulent nature and self-organization state of electromagnetic plasma turbulence[4] in space and galaxies, as well as the collisionless particle transport and nonlocal wave-energy transfer in magnetically confined systems.

References
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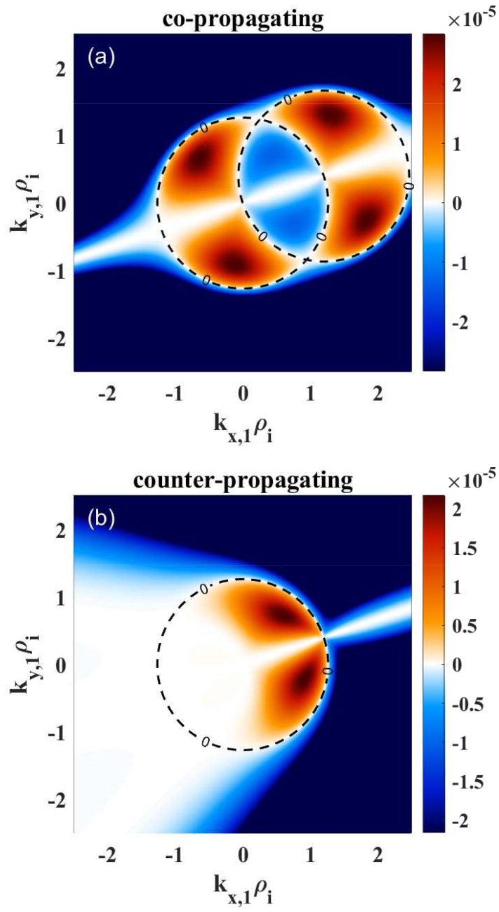

Figure 1. Intensity profiles of the nonlinear drive for (a) all three KAWs being co-propagating or (b) one of the sidebands being counter-propagating with respect to the pump wave.