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Three-wave coupling between shear Alfvén waves and kink-unstable magnetic flux ropes

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Kink waves (arising from unstable magnetic flux ropes) and shear Alfvén waves occur simultaneously in plasmas ranging from solar prominences, the solar wind, magnetic fusion devices, and planetary magnetotails. The linear and nonlinear properties of both types of waves have long been studied, but nonlinear interactions between such waves have received scant attention. In particular, in the case of the solar atmosphere, nonlinear interactions that generate cross-field structures that approach dissipation scales could have an impact on the energy budget of the solar corona heating problem. Here we experimentally investigate a three-wave interaction between a linearly driven shear Alfvén wave and a large amplitude kink oscillation that drives energy towards dissipation scales.

These experiments are performed in the Large Plasma Device at UCLA. Flux ropes are generated using a LaB_6 cathode discharge (with L=18 m and $0.01< \beta < 0.1$.) The flux rope (r = 8 cm) is embedded in a lower-density, larger (r = 30 cm) ambient plasma produced by a second, BaO cathode. Shear Alfvén waves, with azimuthal mode number, m = -1 are launched using an internal antenna at 100 kHz. When the flux rope is driven kink unstable, m = +1 oscillations arise, and the shear wave develops multiple sidebands, each separated by the kink frequency (~10 kHz). Data are acquired of the magnetic oscillations in planes perpendicular to the background magnetic field, from which the axial current density fluctuations are derived and displayed in Figure 1 for the kink, launched Alfvén wave, and sidebands.

Data are presented that confirm that the sidebands satisfy the three-wave matching conditions from the parent waves: frequency matching along with radial, azimuthal, and parallel wavenumber matching. Additionally, bispectral analysis of the fluctuating magnetic field time series demonstrates a strong phase coherence (b^2>0.9) between the three wave pairs; where b^2 is the squared bicoherence. Altogether, this provides strong evidence that a three-wave interaction is responsible for the generation of the daughter sidebands from the kink Alfvén parent waves. The perpendicular wavenumber spectra, show that the sidebands are driven at decreasing spatial scales, approaching dissipation scales ($k_r \sim \rho_s^{-1} \sim \omega_{pe}/c \sim \rho_i^{-1}$). Further details may be found in a recent publication [1].

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[1] S. Vincena, S. K. P. Tripathi, W. Gekelman, P. Pribyl, "Three-wave coupling observed between a shear Alfvén wave and a kink-unstable magnetic flux rope," *Physics of Plasmas*, 31 (9) 092302, 12pp, (2024).

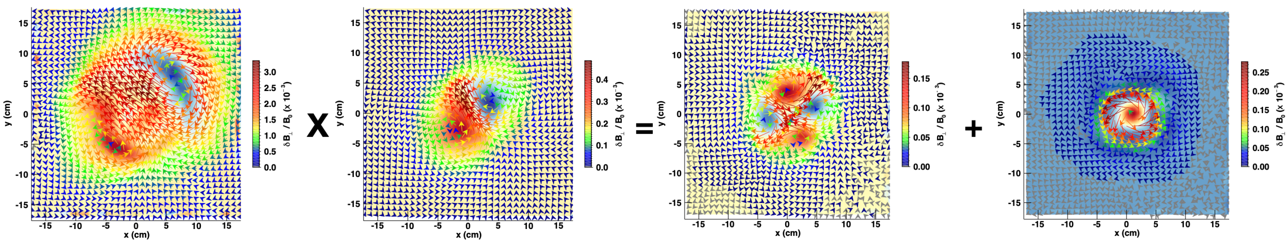

Figure 1 Data acquired on spatial planes perpendicular to the background magnetic field. Magnetic perturbations (vectors) and derived current density (background color) for four modes (left to right): 10 kHz kink oscillation; 100 kHz launched Alfvén wave; sideband at 90 kHz; sideband at 110 kHz.