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Radio signatures of Langmuir-Alfvén turbulence in the solar atmosphere

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Abstract. Radio emissions from the solar active regions can be generated by nonlinear coupling of Langmuir waves with Alfvén waves. Multi-wavelength observations can be used to provide evidence for Langmuir-Alfvén turbulence in the solar atmosphere.

1. Introduction

Space observations of solar radio emissions have provided growing evidence of nonlinear wave-wave interactions involving the electron beam-driven Langmuir waves. Large-amplitude Langmuir waves can produce radio waves by nonlinearly couple to low-frequency magnetohydrodynamic waves such as shear Alfvén waves and fast magnetosonic waves (Chian et al. 1994, 1997). Alfvén waves with high perpendicular wavenumbers are known as kinetic Alfvén waves. A recent study shows that Langmuir waves can excite whistler waves by nonlinearly interacting with kinetic Alfvén waves in the solar corona (Voitenko et al. 2003).

Nonlinear wave equations describing the interaction of Langmuir and kinetic Alfvén waves can be derived from the two-fluid equations and Maxwell equations. Nolinear dispersion relations can be determined from the basic equations by imposing appropriate phase-matching conditions. Voitenko et al. (2003) showed that 3-wave parametric instability involving the decay of a Langmuir wave into whistler and kinetic Alfvén waves is plausible for backward propagating kinetic Alfvén waves. The nonlinear growth rate increases considerably with growing perpendicular kinetic Alfvén wavenumber. The formation of Langmuir-Alfvén-whistler (LAW) turbulence is expected in the regions of the solar corona where the magnetic field is strong and the plasma is dilute so that the electron cyclotron frequency exceeds the plasma frequency. Such condition can be satisfied in the thin underdense filaments guided by the magnetic field lines connected to the low-temperature patches at the coronal base. The growth of the LAW decay instability depends critically on the ratio of the electron cyclotron frequency and the plasma frequency. The presence of kinetic Alfvén waves in the underdense filaments leads to fluctuations of the plasma density and velocity at length-scales varying from 10 to 100 m across the magnetic field and 1 to 10 km along the magnetic field. As the instability is much stronger for antiparallel (i.e., sunward) propagating kinetic Alfvén waves, the density perturbations produced by the Langmuir-driven kinetic Alfvén waves should move sunward. Such fluctuations, moving with the Alfvén velocity along the filaments towards the Sun, should give rise to the scattering of the coronal radio emission. The traces of this scattering from the distant corona down to the active regions may pinpoint the locations where the plasma is dilute and the electron beams are accelerated.

A nonlinear theory of 3-wave coupling involving Langmuir, Alfvén and whistler waves is formulated by Lope & Chian (1996) and applied to the observation of LAW events in the auroral acceleration regions. The effects of pump depletion, dissipation and frequency mismatch in the nonlinear wave dynamics are analyzed. This theory contributes to the understanding of the fine structures of the whistler-mode radio emissions and the amplitude modulation of Langmuir waves.

The chaotic nonlinear evolution of 3-wave LAW events has been analyzed by Chian et al. (2000, 2002). The nonlinear system dynamics can be studied with the aid of a bifurcation diagram, constructed from the numerical solutions of nonlinear wave equations, by varying a control parameter such as the growth rate. A variety of nonlinear dynamical phenomena such as period-doubling route to chaos, intermittent route to chaos, chaotic transitions known as interior crisis, and intermittency induced by saddle-node bifurcation and interior crisis can be identified from the bifurcation diagram. Space and ground observations of solar radio emissions often display intermittent bursty events. The nonlinear dynamical model of LAW events provides a rich theoretical insight to understand the physical processes occurring in the solar active regions.

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