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Damping processes of large amplitude Alfven waves in the solar wind

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Large amplitude, anti-sunward propagating Alfven waves have been observed by in situ measurement in the solar wind plasma[1]. Since previous observational studies suggest that the Alfven waves dissipate with increasing heliocentric distance[2], these waves probably play an important role in generation of turbulent states and heating of plasma in the interplanetary space.

Since linear Landau/cyclotron damping rates of low-frequency Alfven waves are small[3], wave-wave interactions are of great interest to damping processes of large amplitude Alfven waves. Cohen and Kulsrud[4] discussed steepening of envelope of Alfven waves and shock formation by using the multiple time scale expansion. Their work[4] clearly shows that compressible nature of large amplitude Alfven waves affects nonlinear evolution of these waves. Parametric instabilities among the Alfven waves and compressible fluctuations have also been investigated by a lot of authors[5].

It is important that even if Alfven waves themselves are robust for linear Landau/cyclotron damping, parametric instabilities are affected by ion kinetic effects through coupling of Alfven waves with compressible fluctuations. Terasawa et al[6] pointed out that Landau damping of ion acoustic waves suppress the growth of the parametric decay instability. Fla et al[7] discussed a kinetic fluid model[8] and demonstrated that ion kinetic effects make Alfven waves unstable even if these waves are stable in the fluid limit. Later, Araneda[9] presented a hybrid-fluid model of dispersion relations including both modulational and decay instabilities.

In this study, we discuss collisionless damping processes of Alfven waves and associated particle heating/acceleration in the solar wind plasma. Some results are summarized as follows:

(1)Finite temperature effects[A1]

Parametric instabilities of Alfven waves are affected by ion Landau damping of longitudinal waves but also finite Larmor radius (FLR) effect.

(2)Finite bandwidth effects[A2,A3,A4]

Even when linear growth rates are small, modulational instability can be dominant since envelope modulation due to the finite bandwidth becomes “seed” and drive the instability nonlinearly[A2]. Nonlinear Landau damping due to the envelope modulation also causes energy dissipation of Alfven waves, while phase coherence among waves are only generated through the modulational instability[A3,A4]. While the normalized cross helicity is well conserved, the magnetic energy of waves decreases. This results in the conversion of the kinetic energy of transverse wave dynamics of ions (apparent temperature) into real ion temperature[A4]. Theoretically, this corresponds to Bernoulli law accompanying with Alfven wave solutions[A5,A6].

(3)Proton beam effects[A7,A8]

Since the existence of proton beams modifies the dispersion relation, parametric instabilities of Alfven waves are also affected by the beams, even when the beams are stable[A7]. It is also shown that obliquely propagating waves excited by proton beams can promote damping of Alfven waves[A8].

(4)Radial expansion effects[A9][A10]

Nonlinear steepening of envelope modulation of Alfven waves is promoted by “wave shoaling” due to the background inhomogeneity[A9]. Moreover, weak acceleration of the solar wind in the interplanetary space affect the modulational instability[A10].

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