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Evolution of proton beams in the solar wind

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Observations often show that the drift velocity vbi of proton beams relative to the background solar wind decreases with the heliocentric distance, but the ratio of vbi to vA (the local Alfven velocity) does not vary significantly and has a typical velocity ratio of 1<vbi/vA<2 in the solar wind. Electromagnetic ion cyclotron (EMIC) waves have been suggested possibly to play an important role in the deceleration of the proton beams in the solar wind; detailed processes are not proposed. Based on the kinetic dispersion relation solver of PDRK and the empirical model of the solar wind, we investigate the effects of oblique ion-cyclotron (IC) and parallel magnetosonic (MS) instabilities on the radial evolution of the proton-beam drift velocity in the solar wind. The results indicate that the instability thresholds of the IC and MS waves both depend on the local velocity ratio vbi/vA and the ratio of the electron pressure to the magnetic pressure βe for a fixed ratio of beam density to background density nbi/n0, and the critical velocity ratio for the IC (MS) wave increases (decreases) with the heliocentric distance. In particular, the observations by the Helios and Wind spacecraft between 0.29 and 1 AU show that the observed values of vbi/vA are close to or less than the threshold of IC instability at r<rc, but near or below that of MS instability at r>rc, where rc≈ 0.55 AU dependent on nbi/n0. This indicates that the IC instability dominates the dissipation of proton beams at r<rc, and the MS instability controls the deceleration of proton beams at r>rc in the solar wind. Also, one-dimensional (1-D) and two-dimensional (2-D) hybrid simulations are carried out to study the nonlinear evolution of IC and MS instabilities. It is found that these nonlinear wave-particle interactions maintain the proton beam velocity at the marginally stable value below the thresholds of the linear waves, implying that the kinetic energy of proton beams can be further dissipated by nonlinear waves. These results have a potential importance in understanding the evolution of proton beams in the solar wind.