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Wave-particle interactions close to the cyclotron frequency in the expanding solar wind

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We present hybrid simulations of the solar wind expansion performed using an expanding box model. We study the evolution with distance of an initial spectrum of Alfvén waves, and the change in the proton distribution function provided by wave-particle interactions which take place in the plasma when the wave spectrum becomes cyclotron-resonant. We find that also non-linear wave-wave interactions deriving from the parametric decay of the initial spectrum of waves play a role in the proton dynamics. Due to the perpendicular cyclotron heating the proton anisotropy $T_\perp/T_\parallel$ evolves with increasing distance non-adiabatically, and results in agreement with the radial evolution observed by in situ measurements. We find that during the expansion the proton distribution function importantly departs from the initial bi-Maxwellian shape and shows signatures of kinetic interactions with the waves. The final distributions are in agreement with the distributions observed in the solar wind.