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Propagation of non-WKB Alfvén waves in a multicomponent solar wind with differential ion flow

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The propagation of dissipationless, hydromagnetic, purely toroidal Alfvén waves in a realistic background three-fluid solar wind with axial symmetry and differential proton-alpha flow is investigated. The short wavelength WKB approximation is not invoked. Instead, the equations that govern the wave transport are derived from standard multi-fluid equations in the five-moment approximation. The Alfvénic point, where the combined poloidal Alfvén Mach number $M_T = 1$, is found to be a singular point for the wave equation, which is then numerically solved for three representative angular frequencies $\omega = 10^{-3}$, 10^{-4} and 10^{-5} rad s^{-1} with a fixed wave amplitude of 10 km s^{-1} imposed at the coronal base (1 $R_{\odot}$). The wave energy and energy flux densities as well as wave-induced ion acceleration are computed and compared with those derived in the WKB limit. Between 1 $R_{\odot}$ and 1 AU, the numerical solutions show substantial deviation from the WKB expectations. Even for the relatively high frequency $\omega = 10^{-3}$ rad s^{-1}, a WKB-like behavior can be seen only in regions $r > 10\ R_{\odot}$. In the low-frequency case $\omega = 10^{-5}$ rad s^{-1}, the computed profiles of wave-related parameters show a spatial dependence distinct from the WKB one, the deviation being particularly pronounced in interplanetary space. In the inner corona $r < 4\ R_{\odot}$, the computed ion velocity fluctuations are considerably smaller than the WKB expectations in all cases, as is the computed wave-induced acceleration exerted on protons or alpha particles. As for the wave energy and energy flux densities, they can be enhanced or depleted compared with the WKB results, depending on ω. With the chosen base wave amplitude, the wave acceleration has negligible effect on the ion force balance in the corona. Hence processes other than the non-WKB wave acceleration are needed to accelerate the ions out of the gravitational potential well of the Sun. However, at large distances beyond the Alfvénic point, the low-frequency waves can play an important role in equalizing the speeds of the two ion species considered.