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Self-consistent kinetic PIC simulations of collisionless supercritical shocks in astrophysical plasmas with multiple ion species

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Supernova remnant and heliopause termination shock plasmas may contain significant populations of minority heavy ions such as alpha-particles, with relative number densities n_α/n_i up to 50%. Fully self-consistent kinetic simulations of quasi-perpendicular, supercritical shocks can show non-steady, reforming solutions with consequences for ion acceleration local to the shock. We present the first set of particle-in-cell simulations that span the entire range of values of n_α/n_i from zero to one, where the two ion species and electrons are all treated fully self-consistently. These '1.5D' simulations evolve the full three dimensional particle trajectories and electromagnetic vector fields as a function of one space co-ordinate and time. The simulated supercritical (Mach number ~ 8) shocks have perpendicular geometry, plasma $\beta = 0.15$, upstream magnetic field $B_1 = 10^{-7}$T and particle density $n \approx 10^7$m^{-3}. Crucial to the time evolving phenomenology of the shocks and particles at different n_α/n_i are the interplay between the differing characteristic gyroscales of the two ion species. Ions can gain energy both directly by acceleration in the electromagnetic foot-ramp region of the shock, and in the strongly fluctuating fields downstream. The downstream field fluctuations are driven by the free energy that both ion species gain in their initial interaction with the shock. The details of all these processes, and their efficiency for energization, are found to depend on n_α/n_i.

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