A comparison of relativistic particle integrators in a fast magnetized flow

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The particle-in-cell (PIC) method is one of the most important methods to study complex plasma phenomena in space. Basic frameworks and detailed numerical schemes for PIC simulation have long been established. For example, the Boris (1970) integrator to advance particles was proposed a half century ago. However, there is a renewed attention to basic numerical schemes for PIC simulation, in particular in particle integrators. For example, Vay (2008) and Higuera & Cary (2017) have proposed numerical schemes to preserve the force-free condition, E + V x B = 0, which is ideal to study fast magnetized flows. The authors have also proposed higher-accuracy extensions of the popular Boris scheme (SZ & Umeda 2018, SZ & Kato 2019).

In this contribution, we will present a comparison of various particle integrators for PIC simulation. Carrying out 14,000 long-term test-particle simulations, we have carefully checked particle motions in the electromagnetic field, which is relevant to perpendicular shocks. We have found that the popular Boris solver numerically accelerates particles. The boost amplitude is proportional to (delta t)∗∗2. One can suppress the boost by using higher-accuracy Boris-type schemes. The force-free schemes are supposed to be free from the boost, however, surprisingly, we have found that the Higuera-Cary scheme often decelerates particles. We will present second-order theories on the force balance and the angle accuracy to explain the numerical acceleration/deceleration.