A large-amplitude electromagnetic wave excited in relativistic shocks

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Abstract

The origin of cosmic rays has been a long-standing problem in astrophysics. Fermi shock acceleration in supernova remnants is considered a plausible model for the origin of galactic cosmic ray. On the other hand, the acceleration mechanism of high energy cosmic rays has not been understood yet. Recently Chen et al. (PRL, 2002) discussed the possibility of particle acceleration by the large-amplitude Alfvén waves and proposed that the ultra-high energy cosmic rays may be generated by the wakefield acceleration (Tajima and Dowson, PRL, 1979). Since then the acceleration mechanism attracts interests in astrophysical field. Lyubarsky (ApJ, 2006) suggested that a large-amplitude electromagnetic precursor waves, which is excited in the relativistic shock front by synchrotron maser instability (Hoshino and Arons, PoP, 1991), induces the electrostatic field and argued that it may be responsible for the particle acceleration. Hoshino (ApJ, 2008) extended the previous studies and demonstrated the efficient particle acceleration by the incoherent wakefield induced by the ponderomotive force of the precursor waves in the upstream region of the relativistic shock wave by using one-dimensional Particle-In-Cell (PIC) simulation.

In two-dimensional systems, however, several problems about the wakefield acceleration may arise due to the nature of the precursor wave. One is the problem of wave coherence of the precursor wave. The wave coherence is required for the ponderomotive force which induces the wakefield. Another problem is the generation of precursor wave under a competition between synchrotron maser instability and Weibel instability. The growth rate of the synchrotron instability might get smaller than that in one-dimensional systems due to the Weibel instability, and the amplitude of the precursor wave might be insufficient to cause the wakefield acceleration. As the previous one-dimensional simulations could not solve these problems, we investigate in this study the nature of the precursor waves in relativistic shocks by using the two-dimensional PIC simulation and argue the possibility of the wakefield acceleration in two-dimensional systems. In this presentation, we compare two-dimensional simulations to one-dimensional simulations, and discuss that the amplitude of the precursor wave in two-dimensional systems is large enough to induce the wakefiled acceleration even if Weibel instability occurs.