相対論的衝撃波における大振幅電磁波

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Large-amplitude electromagnetic precursor waves in relativistic shocks

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The origin of cosmic rays has been mystery for a long time in astrophysics. Diffusive 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 is still far from fully understood. Recently Chen et al. (PRL, 2002) proposed the particle acceleration by the large-amplitude Alfven waves in relativistic shocks as a model of the generation of ultra-high energy cosmic rays, based on the wakefield acceleration mechanism (Tajima and Dowson, PRL, 1979). Since then much attention has been given to the wakefield acceleration mechanism in astrophysical field. Lyubarsky (ApJ, 2006) suggested that large-amplitude electromagnetic precursor waves, which are excited in the shock front by synchrotron maser instability (Hoshino and Arons, PoP, 1991), induce 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 wakefields induced by the ponderomotive force of the precursor waves in the upstream region of the shock wave by means of one-dimensional Particle-In-Cell (PIC) simulation.

In two-dimensional systems, however, several problems about the wakefield acceleration may arise because of the nature of the precursor wave. One is the problem of wave coherence of the precursor wave. The wave coherence is essential for the ponderomotive force, which induces the wakefield acceleration. The precursor waves may overlap with each other, and the wave coherency may be broken. 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. Since the previous studies in one-dimensional systems could not solve these problems, we investigated 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. Our simulations were performed with high spatial resolution in order to capture the precursor waves because growth rates of the synchrotron maser instability at high harmonics are significantly large. We observed that large-amplitude, semi-coherent precursor waves were excited in two-dimensional, relativistic shocks and found that the amplitude of the precursor waves was large enough to induce the wakefield acceleration, even if Weibel instability occurs. In this presentation, we compare two-dimensional simulations to one-dimensional simulations, and discuss the possibility of wakefield acceleration in multi-dimensional, relativistic shocks.