

Electron accelerations at super-high Mach number shocks: 2D PIC simulations

MATSUMOTO, Yosuke^{1*}, HOSHINO, Masahiro²

¹Graduate School of Science, Chiba University, ²Graduate School of Science, the University of Tokyo

Plasma kinetic processes at collision-less shocks have been investigated and recognized as important for injecting electrons towards so-called the diffusive shock acceleration mechanism. The shock surfing acceleration is one of the prominent mechanisms that can quickly accelerate the electrons at the leading edge of the shock foot region by DC electric fields. The underlying mechanism of the shock surfing acceleration is the plasma kinetic process between the reflected ions and the incoming electrons that leads to the excitation of Buneman instability.

We have examined electron acceleration mechanisms at high Mach number shocks by means of two-dimensional PIC simulations with a large ion-to-electron mass ratio. We found the electrons are effectively accelerated at a super-high Mach number shock ($M_A \sim 30$ in the shock-rest frame). The shock surfing acceleration is an effective mechanism for accelerating electrons toward the relativistic regime even in two dimension. An additional acceleration by the strong electric fields at the shock surface further energized the pre-accelerated electrons up to $\gamma \sim 9$. These two step accelerations are found only in the super-high Mach number shock with a low upstream electron β_e condition.

The conditions of the electron shock surfing acceleration toward the relativistic regime have been derived from one-dimensional arguments [Cargill and Papadopoulos; 1988, Papadopoulos, 1988]. These simple estimations still hold in the present two-dimensional simulations. While all our simulation runs satisfies the unstable condition of the Buneman instability, the shock surfing acceleration was observed in two simulation runs which also satisfied the trapping condition of accelerated electrons by the excited electric field. A similar aspect holds in recent two-dimensional PIC simulations with different parameters from our simulation runs [Umeda et al., 2009; Riquelme and Spitkovsky, 2011].

Exception is also found in a high β_e condition. In this run, the Buneman instability was destabilized in the foot region. However, its peak amplitude is not so large that electrons can be escaped from the trapping region before reaching the relativistic regime. A similar exception was also found by Kato and Takabe [2010]. Although their linear analysis revealed that the foot region in their simulation result was destabilized by the Buneman instability, the resultant energy spectrum showed a Maxwellian like what we see in the present study. These results indicate that we cannot simply understand the high electron β_e simulations from the linear and quasi-linear theories of cold plasma, and detailed analysis of the saturation mechanism of the Buneman instability with finite electron temperature effects is necessary.

Keywords: Supernova remnants, collision-less shock, electron acceleration, high performance computing