

論文の内容の要旨

Numerical Study on Synchrotron Maser Emission and Associated Particle Acceleration in Relativistic Shocks (相対論的衝撃波におけるシンクロトロンメーザー放 射及び付随する粒子加速の数値的研究)

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Relativistic shocks are ubiquitous in the Universe as a consequence of interaction between relativistic plasma outflow and interstellar medium, in which synchrotron maser instability produces intense electromagnetic precursor waves. Particles are reflected off the shock-compressed magnetic field and start gyrating. A ring-like momentum distribution of electrons is naturally formed at the shock front and induce the instability. The synchrotron maser emission from relativistic shocks is newly suggested as the emission mechanism of fast radio bursts and attracts more attention from astrophysics. Furthermore, recent one-dimensional simulations of relativistic shocks show that longitudinal electrostatic waves, which are called wakefields, are induced in the wake of the large-amplitude electromagnetic waves via parametric decay instability and that nonthermal particles are generated during the nonlinear collapse of the wakefields. This particle acceleration may explain the origin of ultra-high-energy cosmic rays, which is a long-standing problem in astrophysics.

Although the synchrotron maser instability in the context of relativistic shocks are important for the coherent emission from astrophysical sources and cosmic ray acceleration, it has so far been discussed solely with one-dimensional simulations. In multidimensional systems, inhomogeneity such as Weibel instability can appear in the

transverse direction of the shock and disturb the ring distribution of electrons in the shock transition. Consequently, the wave emission may be inefficient or completely shut off. In addition, the wakefield amplitude may not be sufficiently large to affect the incoming particles because the ponderomotive force exerted by the large-amplitude electromagnetic precursor waves may decrease due to the oblique propagation. Earlier two-dimensional simulations of relativistic shocks indeed demonstrated that the precursor waves were seen only in the initial phase and that the nonthermal particles are not generated. These results are in clear contrast to the previous one-dimensional simulations.

However, according to our numerical convergence study, the spatial resolution used in the earlier two-dimensional simulations is insufficient for an accurate estimate of the synchrotron maser emission because the precursor waves are high-frequency electromagnetic waves. In addition, the application of digital filtering used to suppress the numerical Cherenkov instability may filter both physical and unphysical electromagnetic waves and underestimate the wave emission efficiency. Therefore, the previous two-dimensional simulations are numerically inadequate to treat the synchrotron maser emission and the particle acceleration in multidimensional relativistic shocks.

In this thesis, by using numerically accurate simulations, we correctly evaluated the synchrotron maser emission in two-dimensional relativistic shocks. Our simulations of pair shocks showed that the large-amplitude precursor waves continue to persist with substantial amplitude, even at a considerably low magnetization rate, where the Weibel instability dominated the shock transition. Synchrotron maser instability can coexist with Weibel instability because the typical scale is much larger than that of the Weibel instability at low magnetization. We investigated the dependence of upstream magnetic field orientations and confirmed that the intense precursor wave is generated regardless of the magnetic field configuration. This result strongly indicate that the intense coherent emission is intrinsic to relativistic shocks. In ion-electron plasmas, the wave amplitude is significantly enhanced by a positive feedback process associated with ion–electron coupling through the wakefields for high magnetization. The wakefields collapse during the nonlinear process of the parametric decay instability in the near-upstream region, where both ions and electrons are accelerated by the motional electric field in the upstream and produce clear nonthermal tails in the particle energy spectra measured in the upstream rest frame. On the basis of the simulation results, we discuss the applicability of the synchrotron maser emission and the particle acceleration for the high-energy astrophysical objects.