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Linearly Polarized Coherent Emission from Relativistic shocks

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The origin of fast radio bursts (FRBs), which are extremely bright and millisecond duration pulse at radio frequency, is one of the unsolved problems in astrophysics [1]. Magnetars are often invoked for the progenitor, which is supported by the recent discovery of FRB 200428 associated with a galactic magnetar. Many observations of FRBs indicate that FRBs must be coherent emission in the sense that coherently moving electrons radiate electromagnetic waves. One of the promising coherent emission mechanisms is synchrotron maser instability (SMI) in relativistic shocks induced by the magnetar flares [2-6]. The SMI, which is called cyclotron maser instability in the weakly relativistic context, is also known as the emission mechanism of coherent radio sources such as auroral kilometric radiation at Earth and Jovian decametric radiation and has been widely studied in the study of space plasma [7]. In the shock transition, the incoming electrons begins to gyrate due to the shock-compressed magnetic field and the ring-like momentum distribution is naturally, generated, which triggers the SMI. The fundamental properties of the SMI in relativistic shocks have been studied by using particle-in-cell (PIC) simulations and have been confirmed that the coherent emission is intrinsic to relativistic shocks [8-10]. The SMI in the context of relativistic magnetized shocks can self-consistently convert the incoming flare energies into coherent emission, and thus it attracts more attention from astrophysics.

The observed rotation measure of some FRBs indicates the magnetoionic environments of the sources, and thus relativistic shocks can be induced in baryon-loaded shells. However, previous PIC simulations consider pair (electron-positron) plasmas and the wave properties in ion-electron plasmas are not fully understood. The observational fact that FRBs often exhibit the high degree of linear polarization constrains the emission mechanism as well. Previous 2D PIC simulations demonstrate the excitation of the two linearly polarized waves: extraordinary (X) and ordinary (O) mode waves. Three-dimensional shock simulations are required for properly taking into account the both X and O mode wave contribution to the polarization.

In this study, by performing the world's first 3D PIC simulation of ion-electron relativistic shocks, we will demonstrate that large-amplitude electromagnetic waves are indeed excited by the SMI even in 3D and that the wave amplitude is significantly amplified and comparable to that in pair plasmas due to a positive feedback process associated with ion-electron coupling [11]. We also measure the wave polarization and quantitatively characterize the wave properties. Our unprecedentedly large-scale PIC simulations of 3D ion-electron shocks reveal the underlying physical process of the SMI-induced coherent emission and provide the detailed description of the wave properties. Based on the simulation results, we will discuss the applicability of the SMI for FRBs in this talk.

References

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