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Dissipation of electromagnetic energy at relativistic shocks

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Poynting-flux dominated relativistic flows are thought to occur in many high-energy astrophysical environments, including pulsar winds, jets in active galactic nuclei and gamma-ray bursts. In the case of a pulsar wind, the relativistic flow is terminated by a standing shock (the termination shock) occurring at the point where the pressure of the flow equals to that exerted by a surrounding medium. Although neither ideal magnetohydrodynamic (MHD) flows nor ordinary MHD shocks do not convert the dominant electromagnetic energy into the kinetic energy of particles, observations do suggest that the kinetic energy is dominant in the downstream of the shock, indicating the presence of an efficient energy conversion mechanism. Magnetic reconnection is often invoked as a mechanism that annihilates the fluctuating component of magnetic fields originating from obliquely rotating central objects. However, it is suggested that magnetic reconnection cannot provide sufficient dissipation, so that the fluctuating component remains until the wind reaches the termination shock.

Motivated by this, the dynamics of a relativistic shock standing in a highly magnetized wind containing a fluctuating component is studied. The fluctuation is modeled by a circularly polarized magnetic shear wave embedded in the flow (i.e., an entropy mode wave.) The frequency of the wave measured in the shock rest frame is boosted by the relativistic Doppler shift, and thus, can be higher than the plasma frequency in a parameter regime relevant to pulsar winds. This opens up a new dissipation channel. The upstream wave can be converted into electromagnetic waves (or photons) by the discontinuity and the dissipation may be triggered through subsequent instabilities. By utilizing a newly developed relativistic two-fluid code for pair plasmas, such a energy conversion mechanism is actually shown to exist. It is demonstrated that the shock is strongly modified by self-consistently generated intense electromagnetic waves. A precursor region is formed ahead of the shock in which significant amount of the electromagnetic energy is dissipated into particles. It is found that an initial highly magnetized wind is converted into a particle-energy-dominated, non-relativistic flow across the shock, as required by the boundary condition imposed by a surrounding medium.

Keywords: shock, electromagnetic wave, relativistic