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Perspective

Upstream of Collisionless Electron/Ion Shocks, Electron Energization Dynamics in Interaction of Self-Generated Magnetic Vortices

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DESCRIPTION

The spectrum of radiation emitted by high-energy particles, as measured by CR and Gamma-Ray Bursts (GRBs) spectra, shows evidence of non-thermal particle acceleration caused by collisionless shocks. These observations, together with numerical simulations of unmagnetized relativistic collisionless shocks, have revealed evidence of electron energization in the shock front as well as electron energization in the electron/ion shock's upstream region.

Supernova remnants, gamma-ray bursts, active galactic nuclei, and binary systems are examples of collisionless shocks in the space and astrophysics plasma environment. Particle acceleration is one of the most important characteristics of astrophysical collisionless shocks. The accelerated particles either depart the acceleration zone and become Cosmic Rays (CR) or interact with ambient backgrounds to produce high-energy photons.

While electron energization at the shock front zone of collisionless shocks is the most studied, electron energization in other large-scale regions of the shocks (for example, in the upstream region) is also of significant interest. The focus of this is on electron energization and acceleration mechanisms in the upstream of relativistic collisionless electron/ion shocks with no external magnetic field during interactions with self-generated magnetic vortices.

Collisionless shocks are believed to be mediated by Weibel instability which leads to fast growth of magnetic field at small scales, plasma isotropization and particle energization at later times. A first phase of magnetic field amplifcation due to Weibel instability happens in the shock front region. A simultaneous stage of magnetic field growth happens due to development of Weibel instability driven by particles moving ahead of shock front, i.e, counter streams, and the incoming cold plasma streams

Electrons that are either reflected or escaped, collision with the shock transition area are known as counter stream electron flow. Biermann battery caused by nonparallel temperature and plasma density gradients, results in the formation of spontaneous nonlinear magnetic modes such as monopole and dipole vortices, in addition to Weibel instability. With no external magnetic field, we have shown that Magnetic Vortices (MVs) can arise self-consistently in the upstream of electron/ion collisionless shocks. The interaction starts with the formation of quasi-linear elongated MVs, which eventually merge to produce circularly shaped MVs (bubble).

At the point when flow energy is transformed into thermal energy, magnetic vortex creation happens. As the MV moves towards the shock front after formation, its magnetic (and electric) fields develop and their longitudinal size shrinks. A significant portion of ion kinetic energy is eventually transformed to thermal energy (13%). At the same time, a small group of particles (including electrons and ions) is accelerated to high energies that exceed the flow particles' initial kinetic energy. The non-thermal components of the electron and ion energy distributions in the vortex region confirm the energy dissipation of the bulk ion beam.

The large inductive transverse and longitudinal electric fields of the evolving MVs in this region immediately accelerate particles in this region, as shown by tracking a significant number of energetic electrons from the non-thermal tail of the energy spectrum. The upstream region's energy distribution exhibits a power-law tail of supra-thermal particles that saturates immediately after the shock originates and remains stable with a power law index.

CONCLUSION

As the number of crossings grows; the energy of the electrons increases. Stochastic particle acceleration and acceleration by direct electric fields are two further methods discussed in the literature. Not just at shocks, but also during reconnection events, these acceleration processes occur. We concentrate on electron energization processes in the upstream region of the shock, when counter stream particles interact with incoming flow, rather than in the shock front. Electrons gain energy only when they interact with MVs' developing fields. The MVs are destroyed before they reach the shock front.

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