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# Shock Waves in the Hot Plasma of Galaxy Clusters

D. Ryu[1], H. Kang[2], and J.-H. Ha[1]
[1] Department of physics, UNIST (Ulsan National Institute of Science and Technology)
[2] Department of Earth Sciences, Pusan National University
e-mail (speaker): dsryu@unist.ac.kr

The hot plasma, called the intracluster medium (ICM), fills the space between galaxies in galaxy clusters. It possesses the largest value of the plasma parameter in the universe, and its nature has started to be uncovered through observations and theoretical work including simulations. In this hot ICM plasma. two distinctive types of shock waves are expected to be induced.

The first category comprises merger shocks, which arise as a consequence of the mergers of subclumps. These shocks have sonic Mach numbers of Ms ~ a few and appear at the outskirts of galaxy clusters. The merger shocks have been observed in X-ray and radio and are named "radio relics". Despite weak shocks, they are capable of injecting particles into the diffusive shock acceleration (DSA) process, aided by various kinetic processes, such as the Bell instability for the ion injection [1] and the Alfven ion cyclotron instability for the electron injection [2], and hence accelerating these particles to high energies.

The second category includes accretion shocks that form due to supersonic gas infall from filaments and voids in the cosmic web. These shocks appear in the periphery of galaxy clusters and are characterized by large sonic Mach numbers of Ms ~ 10 - 100 owing to the relatively low temperature of the infalling gas. In the accretion shocks, ions and electrons are expected to be injected into DSA via a stochastic process mediated by the magnetic field generated through the ion Weibel instability [3].

This talk mainly focuses on the kinetic plasma processes operating at the ICM shocks. Specifically, we present what we have learned so far through particle-in-cell (PIC) simulations and theoretical considerations. We also comment on the remaining outstanding issues that still need to be addressed.

References
[1] J.-H. Ha, D. Ryu, H. Kang, & A. J. van Marle, The Astrophysical Journal, 864, 105 (2018)
[2] J.-H. Ha, S. Kim, D. Ryu, & H. Kang, The Astrophysical Journal, 915, 18 (2021)
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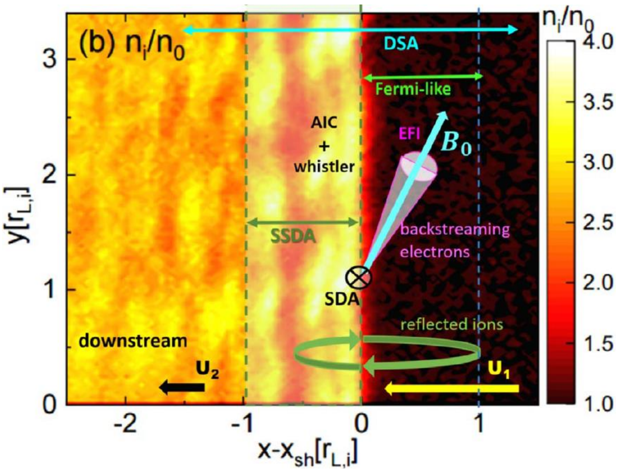


Figure 1. Characteristic Structure of a quasi-perpendicular merger shock in a 2D PIC simulation. The background is the ion number density. The gyromotion of reflected ions (green circular arrows) generates the overshoot/undershoot structure in the shock transition, while the backstreaming of SDA-reflected electrons (magenta cone) induces the temperature anisotropy and the EFI in the preshock region. The colored arrows indicate the regions where DSA (cyan), SSDA (dark green), and Fermi-like acceleration (light green) operate. The labels for the three instabilities, AIC, whistler, and EFI, are placed in the regions where the respective instabilities are excited. During a SDA cycle, electrons drift in the negative z-direction (into the paper here) anti-parallel to the convection electric field. (Ha et al. 2021)