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Using combined PIC and MHD to model particle acceleration in galaxy cluster shocks

Allard Jan van Marle[1], Dongsu Ryu[1], Hyesung Kang[2], Ji-Hoon Ha[1]
[1] Department of Physics, School of natural Sciences, UNIST (Ulsan national Institute of Science and technology),
[2] Department of Earth Sciences, Pusan University
vanmarle@unist.ac.kr

Cosmic rays are particles that have been accelerated by astrophysical shocks, picking up speed as they pass back and forth repeatedly through the shock front. This process changes the characteristics of the gas near the shock as well as the nature of the shock itself. It removes energy from the local gas and the highly energetic particles interact directly with the local magnetic field, changing both its direction and strength, which in turn can lead to instabilities that change the behaviour of the gas.
In order to investigate the particle acceleration process in astrophysical shocks, we need a computational method that can handle both the large-scale structure of the gas as well as the motion of individual particles. We achieve this by using the Particle-in-MHD-Cell [1,2] (PI[MHD]C) approach. This method combines the characteristics of grid-based magneto-hydrodynamics (MHD) with those of the particle-in-cell (PIC) approach by splitting the gas into two components: One, which makes up the larger fraction is a thermal gas that can be treated as a fluid using the MHD approach. The second consists of those particles that start to deviate from thermal equilibrium as they pass through the shock. Their movement is treated through the PIC method. The interaction between the two components is treated in a self-consistent way, using a modified version of Ohm’s Law. This approach allows us to benefit from the computational efficiency of MHD, while still retaining PICs ability to model the movement of individual particles.
Initial tests using the PI[MHD]C method prove that it can successfully reproduce the results that have been obtained previously for high Mach shocks using different methods such as the di-hybrid approach [3,4]. We now extend our tests to low Mach shocks. In our research we focus on the large-scale shocks that exist at the collision fronts between clusters of galaxies. These shocks differ from most astrophysical shocks in that they have a relatively low sonic Mach number (M_S~3) whereas their Alfvénic Mach number (M_A) can be as much as an order of magnitude higher. We wish to determine whether such shocks can effectively accelerate particles and how the shock characteristics influence this process.
Simulations done with a PIC code [5] show that particle acceleration can occur for shocks with a sonic Mach number (M_S~2.25). Using these models as basis we use the PI[MHD]C approach to continue the simulations, while taking advantage of PI[MHD]Cs efficiency to simulate a larger spatial domain for a longer period of time. AN initial result of our simulations is presented in Fig.1, which shows the magnetic field strength, non-thermal particle density and thermal gas density for a shock with M_S=3.2 and M_A =29.2. The magnetic field behind the shock (left) has become turbulent, whereas the up-stream magnetic field shows sign of instability. In such an environment, particles can be accelerated efficiently.

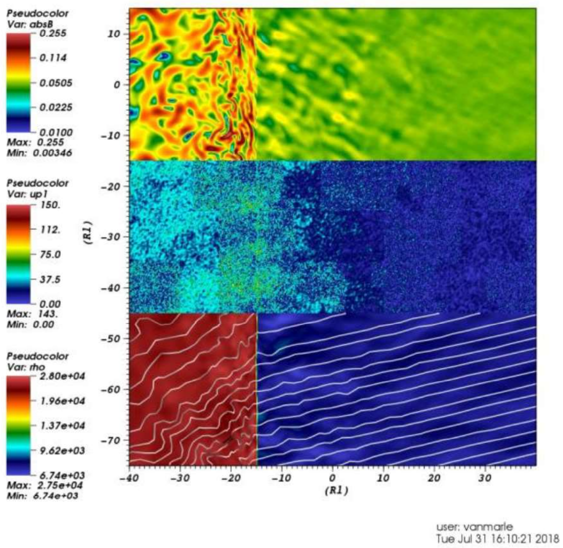

Figure 1. From top to bottom: Magnetic field strength, non-thermal particle density,, and thermal gas density + magnetic field lines for a low sonic, high Alfvenic shock. The field is clearly distorted, creating an environment, suitable for particle acceleration

References
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