Particle Acceleration by Relativistic Shocks Propagation to Inhomogeneous Media

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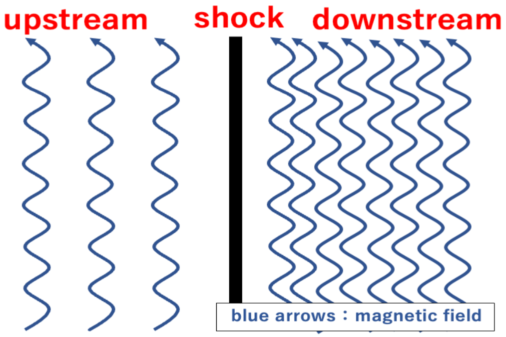
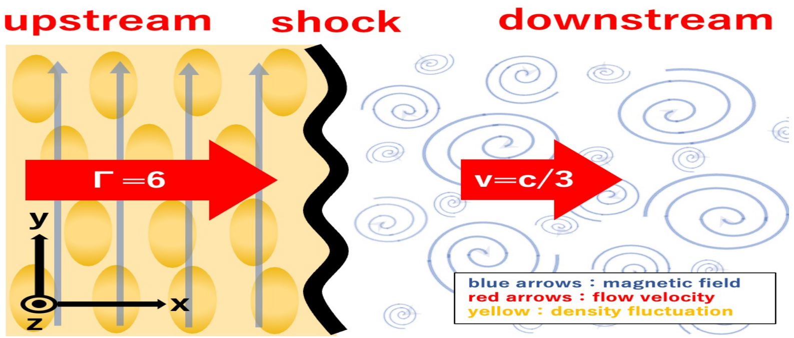
1 Motivation

・Diffusive Shock Acceleration (DSA), which accelerates cosmic rays by diffusing back and forth across the shock wave, is though to be. Nevertheless, for relativistic shock, it is difficult for cosmic rays to go back and forth around the shock for several times.
・However, some observations, such as γ-ray bursts, suggest that particles can be accelerated by the relativistic shocks.



・In previous research(Lemoine et al. 2006, Niemiec et al. 2006), the downstream magnetic field was assumed to be a shock-compressed structure



・In this work, we consider relativistic shocks propagating to inhomogeneous media.
・The downstream turbulence amplifies the shock-compressed magnetic field.

Can particles go back to the upstream region in the turbulent magnetic field?

2 Simulations

・First, we perform 3D relativistic MHD simulations (provided by Y. Matsumoto and T. Omura) to obtain electromagnetic fields in the shock downstream region. Then, we perform test particles simulations in the electromagnetic field.

$$m\frac{d\vec{v}}{dt} = q\left(\vec{E} + \frac{\vec{v}}{\gamma c}\times\vec{B}\right).$$

・MHD simulation box: 1000 x 100 x 100 grids
・Shock rest frame
・density fluctuation is compressed by $1/\Gamma$ in the x direction.
・the density profile is following

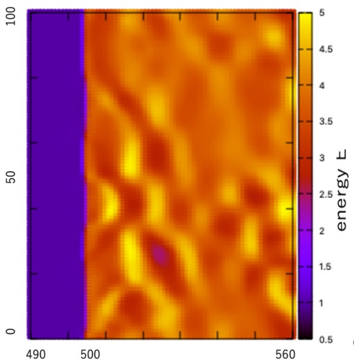
$$\rho = \rho_0 + \sum_{k=-4}^{4}\sum_{j=-4}^{4}\sum_{i=1}^{4} 0.1\sin\left((i*x*\Gamma + j*y + k*z)*2\pi/L_y + \alpha\right)$$

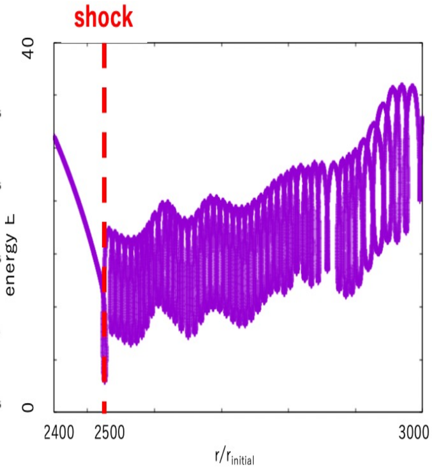
,where L_y is box size (100 grids) and α is random phase.

・The computational system is my MacBook pro with M1 chip.

3 Results

$|B|/B_0$ around the shock





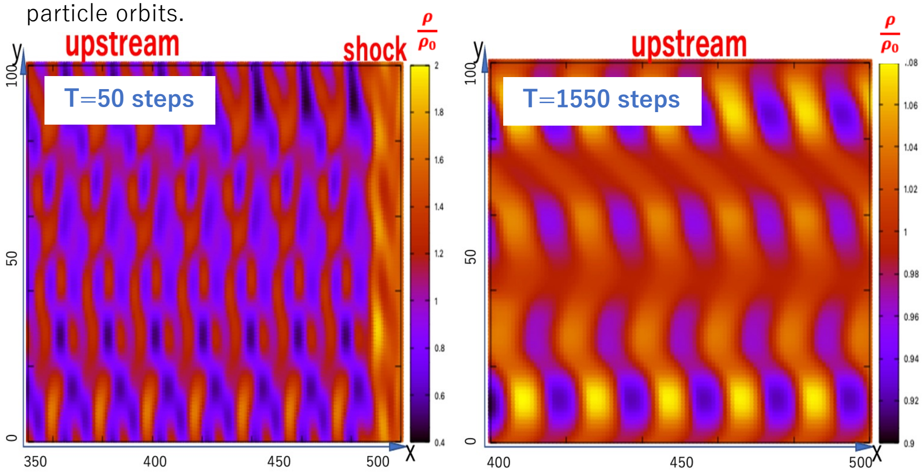
The left panel shows the magnetic field strength in the downstream region. The right panel shows the particle trajectory. No particle goes back to the upstream region. Some particles are accelerated by turbulence in the downstream region.

4 Discussion

The results in this work are very doubtful because of the following reasons.

The spatial resolution in the relativistic MHD simulation is poor. The upstream density structure becomes uniform as time goes on due to the numerical dissipation. We need a higher spatial resolution.

In this work, we use a snapshot data of the relativistic MHD simulation as a first step. We need to solve simultaneously the relativistic MHD and test particle orbits.



5 Summary & Future Works

Summary
・We investigated DSA at a relativistic shock propagating to a nonuniform medium.
・In this work, no particles go back to the upstream region, that is, DSA does not work. Some particles are accelerated in the downstream region.

Future Works
・Higher resolution in the relativistic MHD simulation to avoid the numerical dissipation.
・Simultaneous simulations of the relativistic MHD and test particle calculations.
・We are going to perform the above simulation by using the supercomputer "Fugaku".