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Magnetic turbulence by the interaction between a special relativistic shock and an inhomogeneous medium

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Gamma-ray bursts (GRBs) are the most energetic events in the universe. The relativistic jet is emitted from the central engine of GRBs, and it propagates into the surrounding medium, generating a shock wave. The magnetic turbulence is generated when the Weibel instability, which is the plasma kinetic instability driven in some relativistic shock, and the magnetic field strength is amplified. On the other hand, GRB observations show that the magnetic field cannot be explained by the Weibel instability. Therefore, we need to consider another magnetic field amplification.

At the shock front, it interacts with the surrounding inhomogeneous medium. This interaction can drive turbulence in the shock downstream region. Unlike the plasma kinetic instability, this turbulence can be the magnetohydrodynamic (MHD) scale, which is also observationally consistent. However, we do not know the value of the magnetic field amplified by the interaction.

We performed the special relativistic 3D MHD simulation in order to drive the turbulence in the downstream region driven by the interactions. Then we confirm the magnetic field amplification. The results show that the strength of the amplified magnetic field is in good agreement with the GRB observations. The value depends on the parameter of the amplitude of the density fluctuations relative to the background medium, because the forcing power becomes stronger with a larger amplitude of the density fluctuations.

In addition, we analyze the properties of the downstream turbulence. The kinetic power spectra show the Kolmogorov spectra, and the magnetic ones are flatter than those of the kinetic case, which is seen in some previous studies.[1] Moreover, we analyzed the turbulent properties in terms of the compressibility. In the case of the non-relativistic shock waves, where the incompressible component is dominant over the compressive mode, the power of the incompressible mode is comparable to or a little bit smaller than the compressible mode. The magnetic field is amplified by the incompressible mode due to the dynamo effects, this result may cause the difference in the magnetic amplification observed in some numerical studies[2].

We also observed shock-like structures generated by the interactions between the shock and the density fluctuations[3]. Figure 1 illustrates the four-velocity profiles in the plane parallel to the shock propagation direction. The x-direction is the shock propagation direction, and the upper (lower) row shows the compressible (incompressible) components. The panels in the column show the x-, y-, and z-components of the four-velocities. As you can see in the x-components, the shock-like structure is propagating. These shocks can also amplify the turbulence, so that the downstream magnetic field amplification is enhanced by the shocks.

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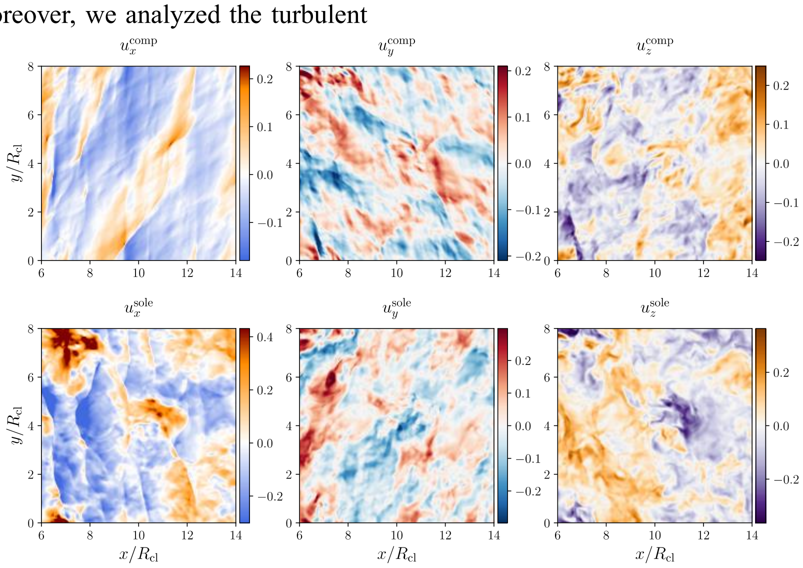

Figure 1. Two-dimensional distributions of u_x, u_y and u_z of the compressive (top four panels) and incompressible (bottom four panels) modes.