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2D MHD Simulations of Internal Shocks and Turbulence in the Reconnection Jet

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Abstract. To explain the origin of hard X-ray emission, we suggest the internal shocks could be created in the reconnection jet and accelerate the energetic particles in the solar flares. We examine its possibility by performing 2D resistive MHD simulations. We use very small very small grid to resolve the diffusion region and remove the effect of numerical noise. As the results, the current sheet becomes thin by tearing instability, and collapses to Sweet-Parker sheet. It becomes unstable again so that the secondary teaing instability occurs. Immediately after the plasmoid ejection, anomalous resistivity sets in and Petschek-like reconnection starts. During the Petschek reconnection, many plasmoids are created by the secondary tearing instability and ejected along the current sheet. The multiple fast shocks are created in the current sheet. We suggest that the internal shocks shown in this paper are possible sites for the particle acceleration in the solar flares.

1. Introduction

The satellites such as Yohkoh and RHESSI observe the hard X-ray emission from the energetic particles in solar environment, for example, at the loop top and foot points of the impulsive flares. They are considered to be accelerated, for example, in the diffusion region or in fast shock at the loop top. The origin of them, however, is not yet fully known. In this paper, we suggest that they could be accelerated at internal shocks in the reconnection jet. To examine its possibility, we perform 2D resistive MHD simulations with a high spatial resolution to resolve the diffusion region.

2. Numerical Simulations and Results

We assume the simplest current sheet created by $B_x = B_0 \tanh(z/H)$, $B_z = B_y = 0$, by using small grid ($dx = dz = 0.013H$) and large simulation region ($L_x = 169.0H$, $L_z = 16.9H$). The grid number is ($N_x = 13000H$, $N_z = 1300H$). We also assume an anomalous resistivity model: $\eta = \eta_0 + \alpha(v_d/v_c - 1)^2$, where $v_d = J/\rho$. The plasma's β is 0.2. Magnetic Reynolds number is $R_m = L_x v_A/\eta_0 = 84500$. In this model, we use very small grids to resolve the diffusion region. The "background resistivity" η_0 is larger than the numerical resistivity due to grid size. Initially, we enhance the electric resistivity only at the center of current sheet for a short time.

As the results, we find that the current sheet evolves as following phases (Tanuma *et al.* 2001): (i) Tearing instability occurs, and the current sheet becomes thin. The current sheet collapses to form Sweet-Parker sheet in the nonlinear phase of tearing instability. (ii) Sweet-Parker-like reconnection occurs. The sheet becomes very long. (iii) Sweet-Parker sheet becomes so long to be unstable. "Secondary tearing instability" occurs in this long sheet, and many plasmoids are created in the diffusion region. (iv) Just after the plasmoid ejection, the anomalous resistivity sets in. Fast (Petschek-like) reconnection starts. In this phase, the reconnection rate is determined by the plasmoid-ejection.

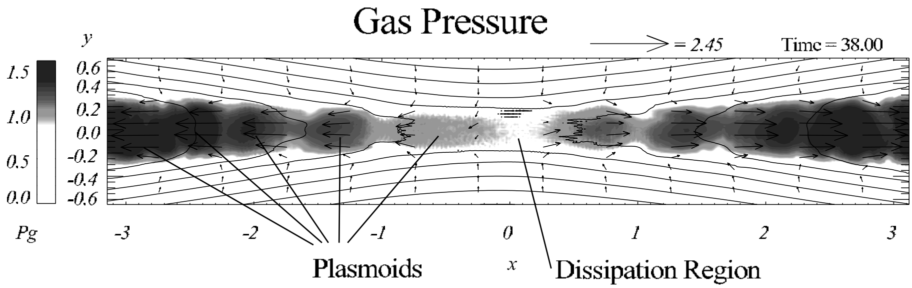

Figure 1. Snapshot of the reconnection region. Many plasmoids are created by the secondary tearing instability in the diffusion region. They are ejected along the current sheet to create the internal shocks.

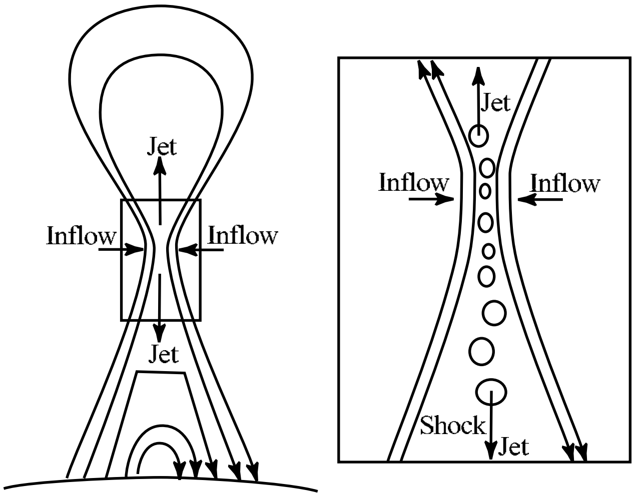

Figure 2. Schematic illustration of the multiple fast shocks in the solar flares.

During fast reconnection, we find that multiple fast shocks are created in the reconnection jet. It is because many plasmoids are created in the diffusion region by the secondary tearing instability, and they are ejected along the current sheet in a non-steady manner (Tanuma & Shibata 2003). The intervals of fast shocks are consistent with the wave length of secondary tearing instability in the diffusion region derived from analytic calculation. Kelvin-Helmholtz(-like) instability would also occur between the jet and ambient gas. The jet becomes in a turbulent situation.

3. Conclusion

We reveal that the fast reconnection occurs after the secondary tearing instability, and that the multiple fast shocks are created by the secondary tearing instability in the reconnection jet. In this paper, we suggest that the multiple fast shocks are possible sites for the particle acceleration in the solar flares.

References

Tanuma, S. et al. 2001 *Astrophys. J.* **551**, 312–332.

Tanuma, S. & Shibata, K. 2003 *Proc. of the 28th Intl Cosmic Ray Conf. (ed. T. Kajita et al.).* pp. 3351-3354. Universal Academy Press.