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Internal Shocks in the Reconnection Jet in Solar Flares: Dependence on Resistivity Model

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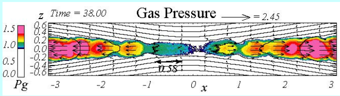


Fig.1

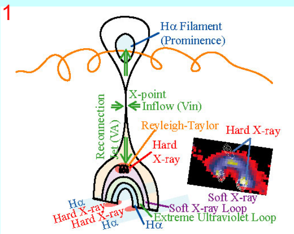
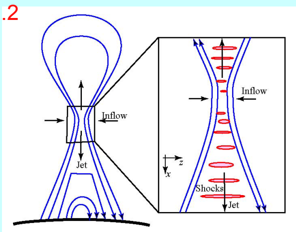


Fig.2

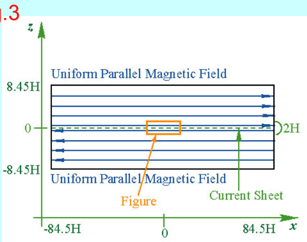


1. Observations of Hard X-Ray Emission from the Solar Flares

Hard X-ray emission from energetic particles are observed in the solar flares (Fig.1).

They are considered to be created in the diffusion region or at a fast shock at the loop top. Their origin, however, is not yet fully known. In this paper, we suggest that they are accelerated by multiple fast shocks that are created by an instability of the diffusion region in the flare (Fig.2). To examine this model, we perform 2D resistive magnetohydrodynamic (MHD) simulations with a high spatial resolution.

Fig.3



2. Numerical Simulations

As the initial condition, we assume the simplest current sheet created by Bx=Bo tanh(z/H) (Fig.3). Plasma beta is 0.2 outside the current sheet. Temperature and total pressure are uniform everywhere. The grid resolution is (0.013H, 0.013H) (uniform). The grid number is (13000, 1300). The simulation region size is (169H, 16.9H). Initial magnetic Reynolds number is Rm=84500. We assume an anomalous resistivity model: h=0.005+10(J/n/vc-1)^2 (if J/n>vc); h=0.005 (J/n<vc), where vc=20. The strong resistivity sets in locally where the drift velocity (J/n) exceeds a threshold. Initially, we put a small resistivity perturbation at the center of the current sheet for a short time.

Fig.4 Typical Model

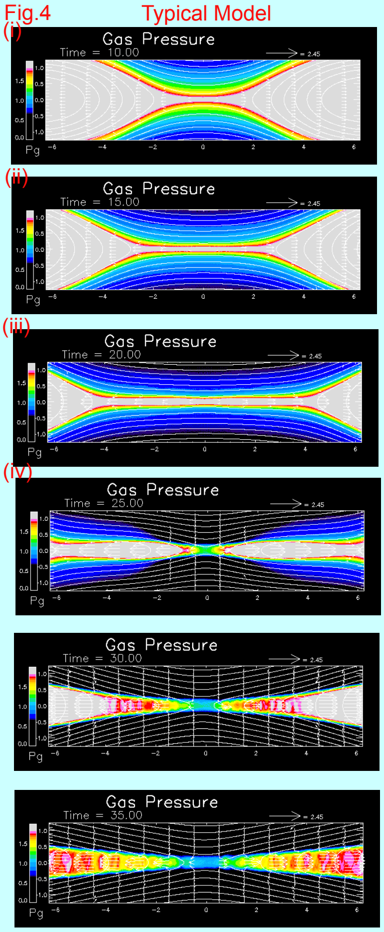
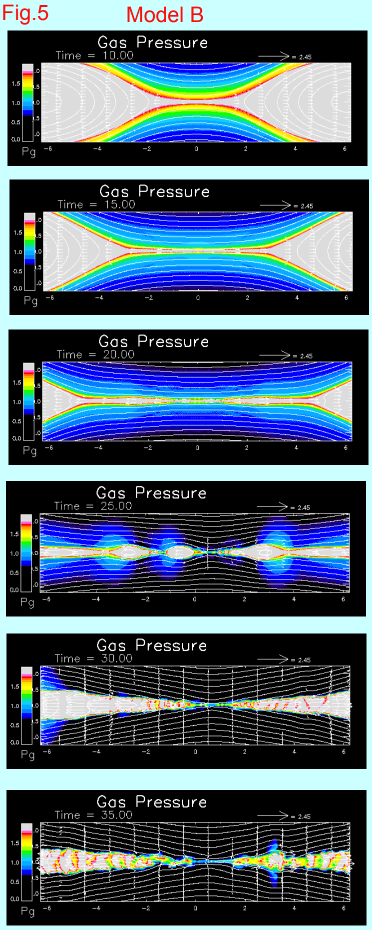


Fig.5 Model B



3. Results

3.1. Typical Model

Fig.4 shows the time evolution of current sheet (Only central region is shown) [1,2,3,4,5]:

(i) Current sheet thinning by the tearing instability,

(ii) Collapse of the curent sheet to a Sweet-Parker sheet,

(iii) Secondary tearing instability occurs in a thin, long current sheet,

(iv) Fast (Petchek-like) reconnection immediately after the plasmoid ejection.

The bursty time-dependent fast reconnection occurs, so that internal shocks are created in the reconnection jet (Fig.3&4). The reconnection produces a turbulence in the late phase. Fig 6 displays the profiles of some variables. It shows that many weak shocks are created[7].

3.2.Model B

The models with different parameters shows the oblique shocks are created by Kelvin-Helmholtz(-like) instability in the jet (Fig.5&7). In these cases,

many strong oblique shocks are created[8]. The detailed study is our future work.

4. Discussion

The multiple fast shocks created in the reconnection jet are possible sites for the particle acceleration in the solar flare [3,5]. The number of accelerated particles is dN/dt<NVS=10^{35} /s, where N, V, S are the electron density, Alfven velocity, and size of jet, respectively. The value is enough larger than the observed value (10^{33-35} /s). The magnetic reconnection and internal shocks could be also the origin of the X-ray gas and energetic particles in the Galaxy [1,2,4].

Fig.6

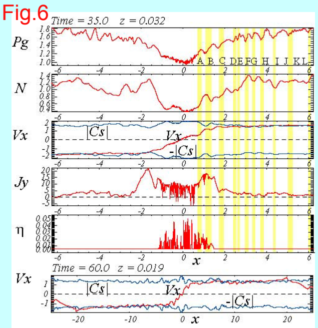
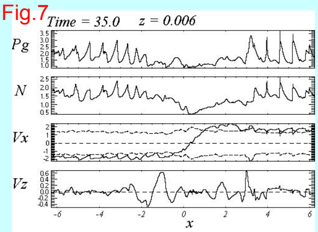


Fig.7



References

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[2] Tanuma, Yokoyama, Kudoh, & Shibata 2003, ApJ, 582, 215

[3] Tanuma & Shibata 2003, in IAU 8th Asian-Pacific Regional Meeting, Vol II, ASP Conf. Ser., 289, 469

[4] Tanuma & Shibata 2003, Proc. of 28th International Cosmic Ray Conf., 2277

[5] Tanuma & Shibata 2003, Proc. of 28th International Cosmic Ray Conf., 3354

[6] Masuda et al. 1994, Nature, 371, 495 (Xray observation shown in Fig1)

[7] Tanuma & Shibata 2005, ApJ, 638, L77

[8] Tanuma & Shibata 2005, in prep.