MHD Simulations of Magnetic Reconnection in the Galaxy: the Origin of Diffuse X-ray Gas and High Energy Particles

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Abstract

Many X-ray and non-thermal emissions are observed in the Galaxy. It is, however, unknown what is the origin of hot($\sim$ 7 keV) diffuse X-ray gas such as Galactic ridge X-ray emission, including non-thermal component. Tanuma et al.(1999) suggested that the X-ray gas are created by magnetic reconnection which occurs in the locally strong($\sim$ 30 μG) interstellar magnetic field in the Galaxy. In this paper, we suggest that the non-thermal emission from high energy particles are also created by the reconnection, and examine this model by performing two-dimensional numerical resistive magnetohydrodynamic simulations. As the results, we find that the fast reconnection starts immediately after the plasmoid ejection, which are created by the secondary tearing instability. The internal shocks are created in the reconnection jet due to the non-steady plasmoid-ejection. In the next phase, the reconnection jet oscillates due to Kelvin-Helmholtz instability, so that the multiple fast (oblique) shocks are created. The magnetic reconnection and fast shocks are possible mechanism to generate the diffuse X-ray gas and high energy particles in the Galaxy.

1. Introduction

The X-ray emissions from diffuse gas are observed in the Galaxy. The origin of some hot components such as Galactic ridge X-ray emission(GRXE) is, however, not known[1]. The non-thermal X-and gamma-ray emissions are also observed at the Galactic plane. The origin of high energy particles is also unknown. We suggested that the hot component($\sim$ 7 keV) of GRXW is created by the magnetic reconnection, in the locally strong ($\sim$ 30 μG) magnetic field[4,5]. The non-thermal emission from high energy particle, however, was not discussed in this “reconnection-heated-model”. In this paper, we propose a new scenario for the origin of hot gas and high energy particles: The X-ray gas is heated by the magnetic reconnection, and the high energy particles are also created at the internal shocks in the reconnection jet[3](figures 1 and 2). In our model, they are confined by helically twisted magnetic field for a long time.

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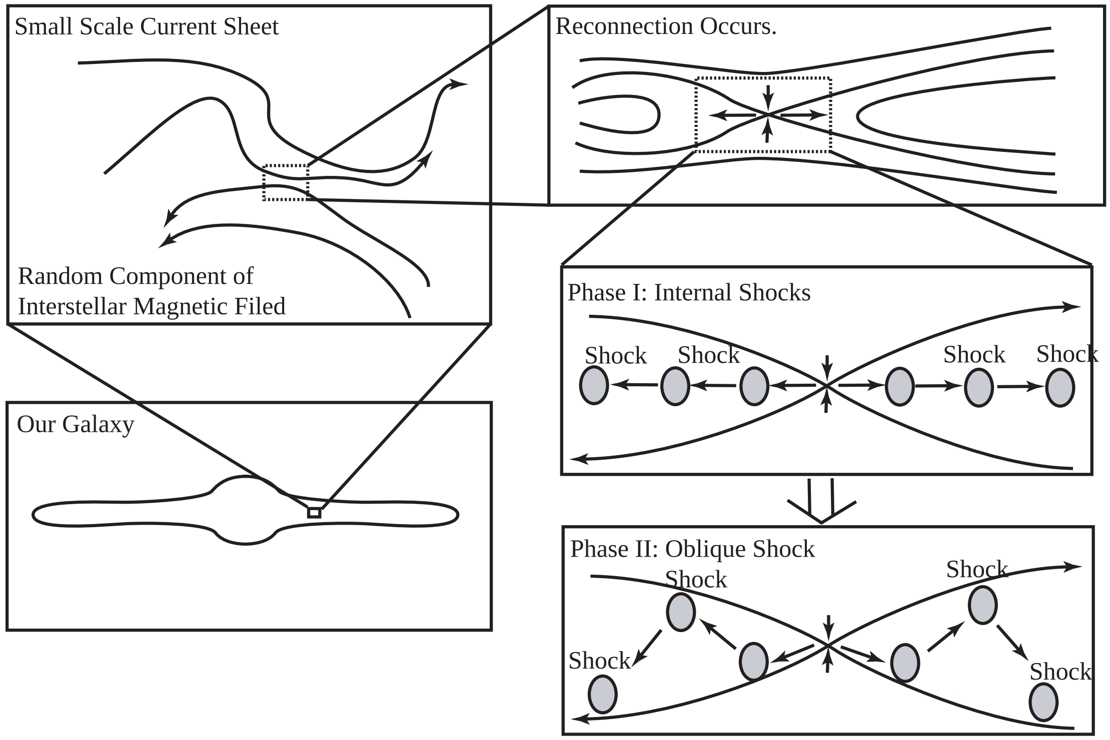

Fig. 1. The schematic illustration of magnetic reconnection in the Galaxy. The magnetic field has many random component at any scale, so that many current sheet are created. If the current sheet is created once, the magnetic reconnection occurs and releases magnetic energy. Furthermore, the multiple fast shocks are created inside the reconnection jet. The fast shocks are possible site for particle acceleration.

2. A New Model

The magnetic field lays almost parallel to the Galactic plane. It has also many random components at many scales. The magnetic field collides with another magnetic field, for example, by Rayleigh-Taylor instability or Balbus-Hawley instability, and creates current sheet. In such situations, the magnetic reconnection must occur and release magnetic energy[4,5]. If the reconnection jet collides with ambient gas, the multiple fast shocks are created inside the reconnection jet. The high energy particles could be accelerated by fast shocks such as supernova shock[2]. In our model[4,5], the magnetic energy is originally supplied from the energy of Galactic rotation, via the Galactic dynamo. And locally strong($\sim$ 30 μG) magnetic field appears at small scale, which is 10 times stronger than mean strength obtained by observation. It is possible if its filling factor is $\sim$ 0.1. During the reconnection, the multiple fast shocks are created inside the reconnection jet, because the reconnection occurs in a non-steady manner[3]. In this paper, we suggest that he high energy particles are accelerated at multiple fast shocks

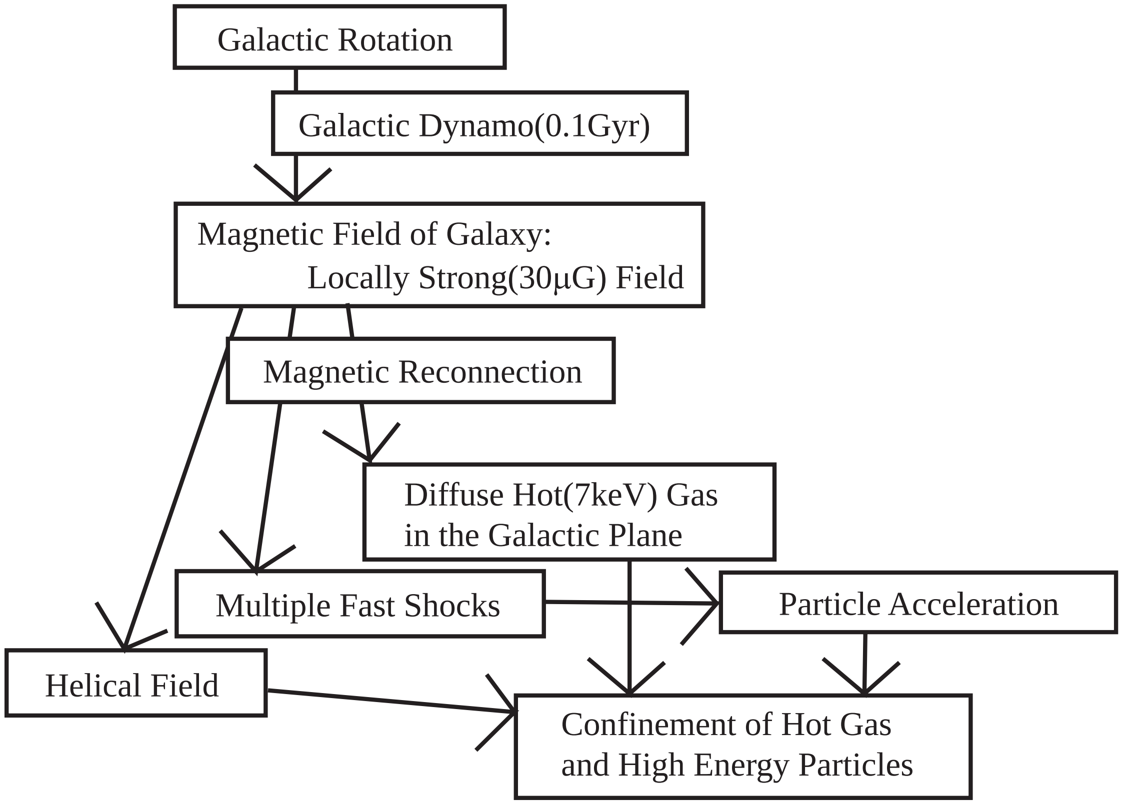

Fig. 2. The possible route to creation and confinement of hot gas and high energy particles. Magnetic reconnection heat the interstellar gas. The multiple fast shocks are also created by the reconnection. It is due to the secondary tearing instability and Kelvin-Helmholtz instability. The fast shocks are possible site for particle acceleration. And the helically twisted magnetic field could confine the hot gas and high energy particles for a long time.

created by reconnection in the Galaxy(figures 1 and 2).

3. Numerical Simulations and Results

We examine the magnetic reconnection in interstellar medium, by performing two-dimensional resistive magnetohydrodynamic(MHD) numerical simulations with high spatial resolution[3,4,5].

As the results, we find that the magnetic reconnection starts long after the initial perturbation, for example, the passage of shock wave from a supernova in a distant through current sheet. The current sheet evolves as follows: (i)Tearing instability occurs, and the current sheet becomes thin in its nonlinear stage. (ii)The current-sheet thinning is saturated when the current-sheet thickness becomes comparable to that of Sweet-Parker current sheet. After that, Sweet-Parker reconnection starts, and the current-sheet length increases. (iii)"Secondary tearing instability" occurs in the thin Sweet-Parker current sheet. Many plasmoids are created and ejected along the current sheet. (iv)As a result, further current-sheet thinning occurs immediately after the plasmoid ejection. Anomalous resistivity sets in, because the gas density decreases in the current sheet. Petschek reconnection starts and heats interstellar gas. Magnetic energy is released quickly while magnetic islands are moving in the current sheet during Petschek reconnection. The released magnetic energy is determined mainly by the interstellar magnetic field strength, The hot gas is confined by the magnetic field for a long time.

During Petschek reconnection, the multiple fast shocks are created[3]. * (Phase I) The internal shocks are created due to the ejection of plasmoids, which are created by the secondary tearing instability. (Phase II) In the next phase, the reconnection jet starts to oscillate, which would be due to Kelvin-Helmholtz(-like) instability. The jet collides with high pressure gas so that the multiple fast shocks are created along the reconnection jet.

4. Discussion and Conclusions

We have suggested that magnetic reconnection is a possible mechanism to generate X-ray gas in Galaxy[4,5]. We suggest that locally strong($\sim 30\ \mu$G) field can create hot(~ 7 keV) component in the Galactic plane, if total size of many reconnection regions is ~ 500 pc^2[4]. Alfvén velocity is $V_A = B(4\pi\rho) \sim 10^8$ cm s^{-1} and plasma β is $\beta = p_g/(B^2/8\pi) \sim 0.2$, if the "cool"($\sim 0.7$ keV) component created by supernova is "re-heated" to hot component by the reconnection. The multiple fast shocks are created in the reconnection jet at the whole reconnection region, due to secondary tearing instability and Kelvin-Helmholtz(-like) instability. The multiple fast shocks in the reconnection jet could accelerate high energy particles at many regions in the Galaxy. Then, we conclude that the non-thermal emission as well as thermal emission from the Galaxy could be explained by the magnetic reconnection.

References

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*Simulation results and application to solar flare are shown in our another article in 28th ICRC Proceedings