Pulse of the Hall term compared to the frozen-in term and the triggering mechanism of magnetic reconnection at the reconnection point

Fucheng Huang
(E-mail:fchuang@ncu.edu.cn)
School of Physics and Materials Science, Nanchang University, Nanchang, China

Abstract The Hall effect closely relates to the decoupling between the motion of ions and that of electrons during magnetic reconnection. It is the key to understand the triggering mechanism of magnetic reconnection. In our previous research result, the energy cascade at the reconnection point is first found (Huang et al. 2018, GRL). It leads to the pulse of the Hall term compared to the frozen-in term at the reconnection point, explaining well the motion decoupling between ions and electrons. In order to understand better the energy cascade at the reconnection point, we will study further the physical process which acts between the energy cascade at the reconnection point and the motion of plasma waves in the reconnection region. The wave-number distribution of both magnetic field and electric field is investigated by use of simulation. The role of Landau damping of KAW in the reconnection region is discussed in detail based on the simulation result. It is also provide a physical mechanism to understand the resistivity which is essential for the colisionless reconnection.

Introductioin The triggering mechanism of magnetic reconnection is important in plasma physics. The energy cascade at the reconnection point during magnetic reconnection has been found in our previous research(Huang et al.2018). For the ideal magnetic fluid, the Hall term is very small compared to the frozen-in term in the general Ohm's law during magnetic reconnection. However, it is found in this study that the latter can be far greater than the former on some special conditions at the reconnection point(about 10 times). It strongly violates the frozen-in condition of plasma, and it permits particles to escape from the magnetic field lines. It creates the favorable conditions for the reconnection of magnetic field lines. In order to understand better the triggering mechanism of magnetic reconnection, the affect of plasma waves in the reconnection region to the reconnection point is dicussed.

spectrum signature at reconnection point

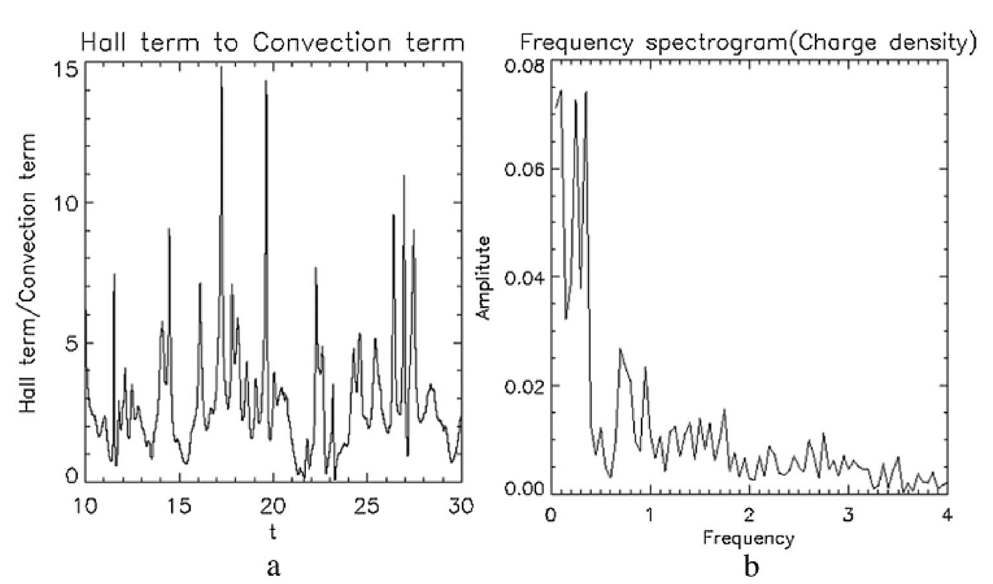

Fig.1 Hall term compared to frozen-in term and frequency spectrogram of charged ion at the reconnection point in the case with guide field (Bg = 0.5) (a) The total value of the Hall term compared to the convection term. (b) The frequency spectrogram of ion charge density at the reconnection point.

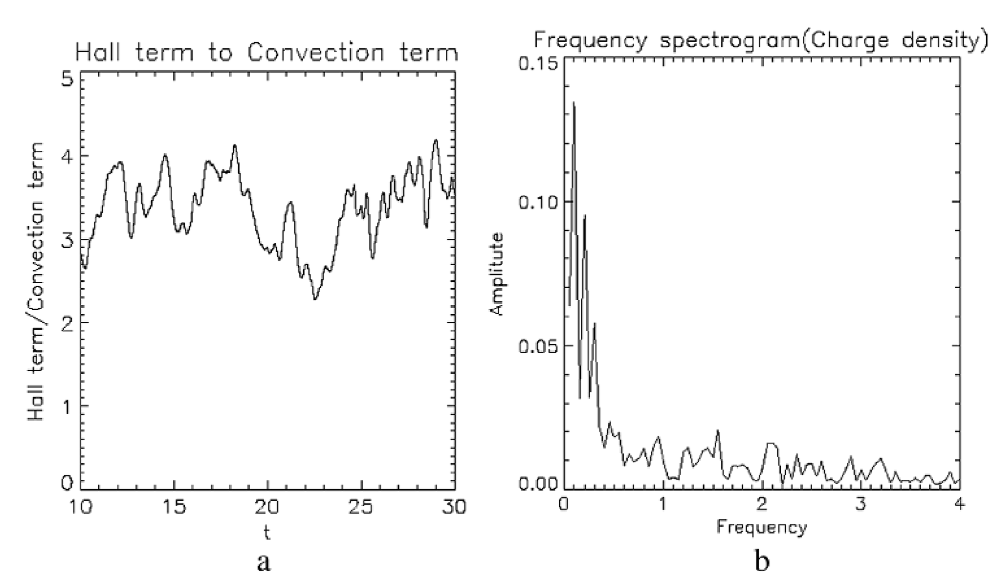

Fig.2 Hall term compared to frozen-in term and frequency spectrogram of charged ion at the reconnection point in the case without guide field (Bg=0). (a) The total value of the Hall term compared to the convection term. (b) The frequency spectrogram of ion charge density at the reconnection point.

Fig.1 and Fig.2 Show the great difference between two cases (the case with guide field Bg=0.5 and that without guide field Bg=0) about the Hall term compared to frozen-in term and the frequency spectrogram of charged ion at the reconnection point. It can be seen in Fig.1a that the Hall term compared to frozen-in term pulses to a great value (about 15 times). However, it doesn't appear in the case without guide field(See Fig.2a). In addition, the frequency spectrogram of charged ion in Fig.1b is broader than that in Fig.2b. This phenomenon is called the energy cascade at the reconnection point by us in the previous study. It means that the energy of plasma waves is cascaded toward the high-frequency part from that of low-frequency part at the reconnection point. And this energy cascade can lead to the pulse of Hall term compared to the frozen-in term in the case with guide field (Huang et al. 2018).

Dispersion relation of KAW energy cascade

Based on the theoretical analysis, the Landau damping of KAW very likely occurs due to the increase of wave vector in the condition of large $k_\perp$ of ion inertial length, the energy cascade can be shown out in the dispersion relation, and it can be written as follows:

$$\omega \propto k_{//} v_A \sqrt{1+(k_\perp \rho_i)^2} \qquad (1) \qquad\qquad \gamma \approx -a\omega k_\perp \rho_i \qquad (2)$$

In Eq.(1) and (2), α is the constant, ρi is the ion gyro-radius, γ is the damping rate, ω is the frequency of KAW, the constant α can be seen in detail in the references (Podesta et al. 2010). It can bee seen from Eq. (1) and Eq. (2) the perpendicular component $k_\perp$ of wave vector is a key factor that enhance the frequency ω and damping rate γ.

A new model for the triggering mechanism of reconnection

It is reasonable to deduce from Eq. (1) that the perpendicular component $k_\perp$ is the key that leads to the high-frequency part generated at the reconnection point in the case with guide field (See Fig. 1), during which the energy of plasma waves cascades into the high-frequency part from the low-frequency part at the reconnection point. Here comes a question: How is Fig.2 explained? In order to answer this question, the plasma waves in the reconnection are investigated by use of hybrid simulation. It can be confirmed in the simulation result that the very strong wave vector $k_\perp$of magnetic-field wave can be formed at the reconnection point in the case with guide field. However, the peak of $k_\perp$of magnetic-field wave is not at the reconnection point, but at its perimeter region in the case without guide field. This simulation result can explain the great difference between Fig.1 and Fig.2. The wave of magnetic-field with strong perendicular vector $k_\perp$ should be the kinetic Alfvén waves(Leamon, 1999). And the resistivity can be also explained well by the mechansim of Landau damping of KAW based on Eq.(2) during this process. More details need be further studied.

References:

Huang, F. C., & Feng, X. (2018), Upward frequency sweeping due to the nonlinear resonance of multiwave coupling and its significant contribution to the Hall effect a t the reconnection point. Geophys. Res. Lett. 45, 11,572–11,580.

Podesta J.J., J.E. Borovsky, S.P. Gary (2010), A kinetic Alfven wave cascade subject to collisionless damping cannot reach electron scales in the solar wind at 1 AU, ApJ 712, 685.

Hollweg, Joseph V. (1971), Nonlinear landau damping of Alfvén waves, Phys. Rev. Lett. 27, 1349-1352

Leamon, R. J., Smith, C. W., Ness, N. F. et al. (1999), Dissipation range dynamics: kinetic Alfvén waves and the importance of βe. J. Geophys. Res. 104,22331–22344.