Nonlin. Processes Geophys. Discuss.,
https://doi.org/10.5194/npg-2018-43-AC1, 2019


Nonlinear Processes in Geophysics
Discussions
Open Access



# *Interactive comment on* "Ion acceleration at dipolarization fronts associated with interchange instability in the magnetotail" *by* Chao Sun et al.

**Chao Sun et al.**

lvhy@buaa.edu.cn

Received and published: 16 January 2019

We greatly thank the reviewer for the comments and suggestions. We have revised and improved the manuscript in response to the reviewer's comments. Following are the description of the revision we have made.

Major comments: I have trouble to understand the initial conditions of the Hall MHD simulation (Lines150-156). The authors claim that. . .

Reply: Thank you for reminding. We noticed that the dimensional units for the magnetic field and plasma velocity we chose before, B0=15nT, V0=750km/s, are too high compared with the observation values. Thus in the modified manuscript, we choose B0=10nT, V0=500km/m, which is more realistic. Under this normalization condition,

Printer-friendly version

Discussion paper

the Ey at the flank has peak value of normalized unit of 4.5 which is 22.5 mV/m. At the dawnside of the DF, Ey is 2.0 in normalized unit which is 10mV/m. The magnitude of electric field is consistent with observation results. Furthermore, the ions are mainly accclerated on the dawnside of the DF and reach energy >6keV.

As far as I understand, the test particle simulation in this manuscript is based on the electromagnetic field from a two-dimensional (2D) Hall MHD simulation. Therefore, . . .

Reply: In our manuscript, the particles, with 90-degree pitch angle and initial locations behind of the DF, move towards the earthward and dawnward and then drift to the tailDiscussion of the limitation of our model has been added in the modified manuscript.

As we know, the Hall electric field is usually formed by the relative behaviors between ions and electrons at certain spatial scales. It is very sensitive to the electon and ion kinetics. Thus, theoretically, the ion kinetic behavior due to Hall electric field is better to study by using self-consistent kinetic models. . .

Reply: The authors think the numerical is self-consistent about the ions motion, Hall electric field and the electric current as well. The ions are carrier of electric current and move along the current lines. Due to the fact that the electric current is tangential with the Dipolarization fronts, most of ions drift to the dawnside of the DF and then drift tailward at the flank. On the other hand, the Hall electric field is contributed by the tangential electric current, and has normal direction to the dipolarization fronts.

Minor comments: 19-20: “all particles". This term is not well defined. The launch information (e.g., initial energy, locations, ...) of these test particles is necessary.

Replay: In the modified abstract, a clear definition of particles we used is described. Please see in line 19-20.

26: “Ey". Please use subscript “y". Same for all the “Bx", “By", “Ex" in the text of this manuscript.

Replay: Thank you. The typo error has been corrected.





Printer-friendly version

Discussion paper

40: “magnetic flux". Does it mean “magnetic flux tube" here?

Reply: Thanks for your reminding.

41: “SC". This abbreviation has not been defined yet.

Reply: Thank you. The sentence has been corrected.

44-48: There are many possible mechanisms related to the DF generation. As a reader, I would like to know, what is the difference of the electromagnetic system of the DF generated by interchange instability than other mechanisms?

Reply: Interchange instability is considered as a possible generation mechanism for the multiple Dipolarization fronts, which have been observed in the near-Earth region in many literatures. One can imagine a picture that as a fast Earthward flow approaches the Earth, it would be braked by the ambient plasma. In the braking region, the tailward gradient of thermal pressure increases and meanwhile the earthward magnetic curvature force increase, which consequently leads to a tailward force. This tailward force enables Earthward fast flows decelerate initially and brake finally in the near Earth plasma sheet. In conjunction with the tailward gradient of plasma density due to the flow braking, the total force brings forth interchange instability in the braking region.

108: “ions trajectories" ! “ion trajectories"

Reply: Thank you. The typo error has been corrected in line 109.

108: “track ions trajectories backward in time". This phrase makes a little confusion. It could mean either running the simulation with negative time step from later time to earlier time or running the simulation with positive time step then check the time history of the trajectories of selected particles. Please specify which scenario is used in this manuscript.

Reply: Thank you. Actually we adopted the latter in our manuscript.

111: “realistic". This word is not used properly. The simulation in this study is only two dimensional and the parameters are not set up based on spacecraft observations for specific events.

Reply: In our manuscript (l.145 - 150), we pointed out that the simulation electric field is too small in the previous MHD simulation. The “realistic” refers to the more realistic electric field.

122: (1) “$\mu$_0” doesn’t look correct in the second and fourth equations. (2) The ”g” should be vector “g”. . . .

Reply: Thank you. The typo error has been corrected.

124: “$\beta$". There is no an explicit “$\beta$" shown before this sentence.

Reply: Thank you. “$\beta$" should be included in the expression of “g”, which has been added in the modified manuscript.

125: “g_x". There is no an explicit “g_x" shown before this sentence. . ..

Reply: Thank you. The missing statements have been added.

129: What is the value of “$\beta$" used?

Replay: $\beta$=2 is plasma beta.

138: According to Guzdar et al. (2010), there is a missing “" on the left hand side of the equation.

Reply: The typo error has been corrected in the modified manuscript.

145: “we set" should be “they set".

Reply: It has been corrected in the modified manuscript.

154-155: What are the values for _Land _R?

Reply: In our manuscript, we took _L=1.5 and _R=1.





Printer-friendly version

Discussion paper

158-159: (1) "The simulation box is 2 RE and 1.5 RE in the direction of x and y". This description doesn't look correct. The simulation results (i.e., the figures) show that there is 4RE in x. (2) Since the simulation used in this study is two-dimensional, please mention this information in the Abstract and somewhere in the "Theoretical and Numerical Model" section. (3) Please provide the information about the number of grid cells in each dimension.

Reply: Thank you. In our simulation, the simulation box is 4 RE and 1.5 RE in the direction of x and y. The numbers of grid cells in x and y directions are set 301 and 201, respectively. The error has been corrected.

161-167: As a reader, I would like to know more details about the test particle simulation: (1) Time step (2) The minimum gyration period of the simulated ions (3) Time integration scheme (4) What happens if the test particle hits the boundary of the simulation box? (5) Since the electromagnetic field is from a two-dimensional Hall MHD simulation, is the test particle simulation also two-dimensional (i.e., do not consider the motion along the z direction)? If so, the test particles should only represent the particles with 90-degree pitch angle.

Reply: In our simulation, we adopt the MHD time step as the test particle simulation time step. At each time step, we use the fourth order Runge-Kuta to solve the equation of motion. Once the test particle hits the boundary, we assume that the ion will remain stationary at the boundary.

172: "more realistic". It is not clear in what aspects this is more realistic. Please specify.

Replay: Compared with previous MHD simulation, we improve the initial condition to obtain a higher electric field. So, the "more realistic" respects the value electric field.

176: "DF". The DF is commonly defined by the abrupt increase of Bz component. However, Figure 1 doesn't show any information about Bz. Please point out in Figure 1 where is DF and how it is defined.

Replay: Actually, the boundary of Bz component abrupt increase is the electric field boundary in Figure1 and we define the DF as the front boundary of Bz component abrupt increase.

182-184: “It should be ...... with a stronger dawnside electric field." It is not clear which asymmetry is mentioned in this sentence. Which electric field component? What time and location in Figure 1?

Reply: From Figure 1 (a), (d) we can clearly see that the dawnward electric Ex, Ey are both larger than the duskward at the region -1 RE < x < 1RE.

184-187: Please specify the locations with either Hall electric field or convective electric field . . .

Replay: Thank you! The asymmetry of distribution of electric field is a subsequence of Lorentz force, according to the Hall electric field, EHall=J$\times$B/ne. Consequently, the Lorentz force along the tangent plane of DF associated with the motions of the decoupled ions leads to the asymmetry of the “mushroom” pattern (see Lu et al. 2013).

192: “simulation box". Should it be “launch region of the test particles", since the results show that some of the particles are located outside this box? In addition, please also provide the DF location in text related to this launch region.

Reply: Thank you. The simulation box is x = -2 RE $\sim$ 2 RE, y = -1.5 RE $\sim$ 0 RE and the launch region is x = -0.9 RE $\sim$ -0.4 RE, y = -1.46 RE $\sim$ -0.04 RE. In Figure2 black line represents the position of the DF.

196: “protons". In this manuscript, both “proton" and “ion" are used. Since there is no any other ion species than proton, it should be better to only use one of them.

Reply: Thank you. In the modified manuscript, only “ion” is used.

197: “black lines indicate the position of DFs". Are the black lines schematic or calculated? What variable is used to determine the black lines? Same comments for Figures

4 and 5b. In addition, what does the Bz profile look like in the launch region? It would be helpful for comparing with observations if there is a line plot of Bz as a function of x.

Reply: Actually the black lines are schematic and we define the black lines by the boundary of the abrupt increase of the Bz component. The Bz profile in the launch region can be shown in Figure I.

Figure 2: (1) (Same for Figure 4) What happens to the particles hitting the simulation boundary in y direction? Are they still moving (e.g., some energetic particles at y=0 in (b) is not there any more in (c)) (2) Why are there more energetic particles in earlier time (b) than those in later time (c)? Do they lose energy?...

Reply: The ions will remain stationary at the boundary once they hitting the simulation boundary in y direction. In our manuscript the particle energy refers to the instantaneous energy, so the energy changes with time.

Figure 3: (1) What time is this plot taken? (2) It should be better to add the initial PDFs so that the initial power law can also be compared. (3) What are the areas to select the particles for plotting each line at different x location? Do these PDF curves include the particles at the y boundary? How much percentage of the energetic particles are at the boundary? If the number is significant, it should be better to perform a simulation with a bigger box.

Reply: In our manuscript, Figure 3 plot the PDFs of total particle energy at t = 187s. The initial power law energy distribution F∼(1+h/($\kappa$T_0 ))^(-$\kappa$-1), which is similar to kappa distribution.

223: “among the multiple fold lines". It is not quite clear what it means. Please rephrase it.

Replay: Thank you. We have rephrased the expression in line 229-231.

226: “small"! → “low”

Reply: Thank you. It has been modified.

247-248: “they move earthward and dawnward with a larger gyration radius due to smaller ambient magnetic Bz." This is about the ions with initial positions ahead of the front. The dawnward motion is not explained well. Is the gyration radius comparable to the scale of the DF? Is the grad-B drift due to the set-up of the Hall MHD magnetic field considered?

Reply: Actually the ions move dawnward because of the Hall electric field in the –x direction. The ion gyration radius is larger than the scale of the DF.

277: “distribution of differential energy flux". How large area is used to select the particles for the calculation? In addition, please change the label of Figures 5c and d to “differential energy flux" instead of “flux".

Reply: We chose 0.1RE*0.1RE as the statistical calculation area and the expression has been polished in the modified manuscript.

278: “azimuthal angle". Which direction is indicated by the zero degree? Please define the directions indicated by different azimuthal angles.

Reply: As shown in the following picture.

279-280: “Ion trajectories with initial positions along different y distances". The meaning of this sentence is not quite clear (e.g., the y distance from where?), please rephrase it. In addition, it is very hard to obtain information from Figure 5b because too many lines overlapping to each other (e.g., can't find the initial position, can't follow individual trajectory, ...).

Reply: Thank you. The ambiguity has been corrected.

286-290: “At about t=146 ...... they are almost simultaneously observed (Figure 5b and 5d)". The meaning of this sentence is not clear, please rephrase it. In addition, why is there a gap around t=153s in Figures 5c and d?

Reply: The ions ahead of the DF accelerated first and the behind one can't be accelerated until they reach the front of the DF. So there exit a gap between these two particles.

Figure 6: Figure 7 shows that the particle obtains large amount of energy from w2 between t=163-165s. It should be better to also show Ey during this time period in Figure 6.

Reply: Thank you. We have added Figure 8 to the manuscript.

316-320: The explanation of the gradual increase of the kinetic energy is not clear. Because the magnitude of $\delta$yˆ- and $\delta$yˆ+ could be due to the magnitudes of the local Bz. At the flank of the DF, different y locations determine whether the particle is in the DF or in the ambient.

Reply: when t > 166 s, the ion kinetic energy gradually increases, which can be interpreted based on the fact that the y-displacement $\delta$yˆ+ (corresponding to the energy increase) is larger than $\delta$yˆ- (corresponding to the energy reduction) in the case where Ey component is almost constant. Since the ions arrive at the ambient of dawnward DF, the magnitude of magnetic field is increase, which results in a high $\delta$yˆ+.

Figure 7: (1) In order to help readers understand the mechanism, it is better to also include the time history of the local Bz, Ex, Ey in this figure. (2) Please provide the information in text on how to calculate the w_1 and the w_2. (3) The comparison between w and w1+w2 is made in Panel (d). Why do the two curves show difference after t=165s?

Reply: Thank you. Figure 8 has been added in the modified manuscript to show the time history of the local Bz, Ex, Ey in Figure 7. Since we used the formula w_1=$\Delta$E_x$\cdot\Delta$x and w_2=$\Delta$E_y$\cdot\Delta$y to calculate w_1 and w_2, so there should be computational error compared to the definition of kinetic energy of particles.

364-365: "Our two-dimensional Hall MHD ...... by the Hall field". This sentence is not written properly. In this study, the acceleration process is analyzed by using the test particle simulation instead of the Hall MHD model.

Reply: Thank you. We have corrected the wrong sentence.

Please also note the supplement to this comment:
https://www.nonlin-processes-geophys-discuss.net/npg-2018-43/npg-2018-43-AC1-supplement.pdf

---

Interactive comment on Nonlin. Processes Geophys. Discuss., https://doi.org/10.5194/npg-2018-43, 2018.

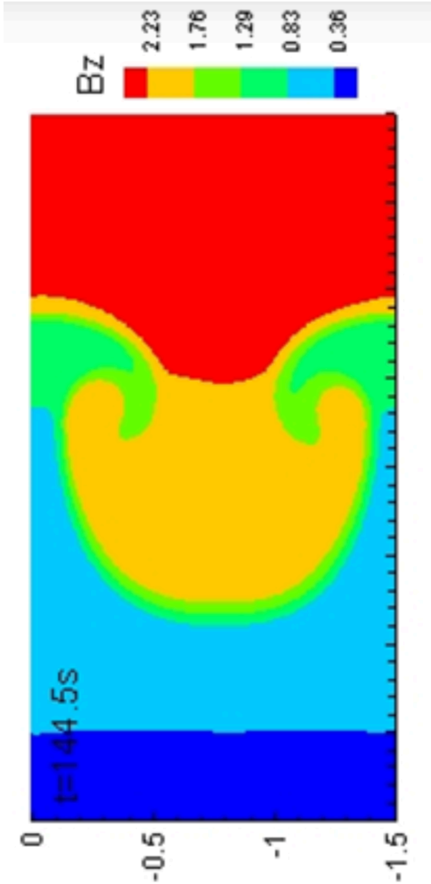


**Fig. 1.**



Printer-friendly version

Discussion paper

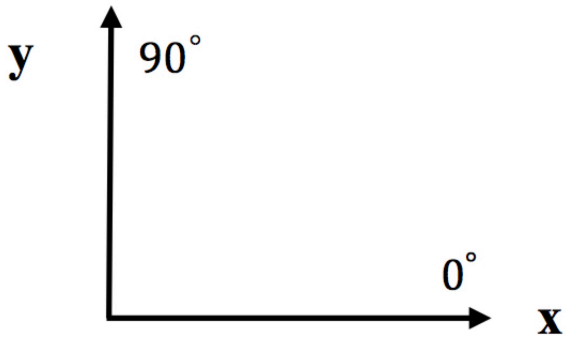


Fig. 2.





Printer-friendly version

Discussion paper