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Nonlinear Processes
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Discussions

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

Anonymous Referee #1

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Discussion paper

Reviewing Comments on Manuscript: “Ion acceleration at dipolarization fronts associated with interchange instability in the magnetotail" by Sun et al.

General comments:

The authors studied ion acceleration at a diporlarization front (DF) produced by interchange instability in the magnetotail. They used a 2D Hall MHD model to simulate the time evolution of a DF associated with interchange instability and launched test particles in the electromagnetic fields from the Hall MHD model to investigate the ion acceleration. Initially, the test particles are launched around the moving DF. They found that the ions initially settled behind the DF obtain higher energization. The resulted high-energy ions (> 13.5 keV) are mainly assembled in the dawnside region of the DF. They conclude that the dawn-dusk component of the Hall electric field on the dawnside of the DF play a important role in the ion energization.

Dipolarization front has been found as an important transient structure contributing to the energy, plasma and magnetic flux transport in the near-Earth magnetotail during substorms based on observations and simulations. Plasma acceleration associated with the DFs is an important component to understand the magnetotail dynamics. Although the Hall electric field related to the DFs has been studied in previous observations and simulations, its effects on the ion acceleration are not well understood. This work investigates the relevent mechanism for the ion acceleration near the DFs. Therefore, it is important for the space physics community and appropriate for the journal. However, there are some comments needed to be addressed properly before publication.

Major comments:

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(a) I have trouble to understand the initial conditions of the Hall MHD simulation (Lines 150-156). The authors claim that “we improve the initial conditions to obtain a realistic electric field" (Lines 148-149) in order to compare with the electric field (normal to the DF) which increases around 10 mV/m at the DFs in some observations. From Figure 1, we can see the E_y has much larger values than E_x at the flank and its peak value is 4.5 (normalized unit) which is 50.6 mV/m. Even at just the dawnside of the DF (e.g., x=-1.0 and y=-0.3 in Figure 1e), E_y is about 2.0 (yellow color) in normalized unit, which is 22.5 mV/m. Thus, the magnitude of the electric field (i.e., the E field normal to the DF) at this location is even bigger than this value by including E_x. Such value is way much larger than observed 10 mV/m in many literature (Runov et al., 2009, 2011; Fu et al, 2012b). In this manuscript, the authors conclude that the ions are mainly accelerated on the dawnside of the DF and reach energy > 13.5 keV. In my opinion, such acceleration may be true but the energy gain by these ions may be overestimated. In addition, according to the Equation (4), there is a signifcant B_z gradient in x direction in the entire simulation box. This could lead to a grad-B drift for the ions to the dawnside of the DF, which is related to the conclusions of this manuscript. Moreover, the transient half-width for the mass density is 0.2 in Equation (3), while that for the B_z is 0.3 in Equation (4). This may lead to artificial local non-equilibrium which may not appear in the observations. Therefore, in general, I hope the authors can provide more discussions about how they select the initial conditions and why these conditions are reasonable.

(b) 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, the test particle simulation is also 2D without the motion in z direction along the field line. In the real magnetotail condition (3D), for the case that the ions are convecting adiabatically with the magnetic field lines and bouncing along the z direction, this 2D simulation may be fine for representing the ion behaviors by projecting ion gyration motion onto this 2D plane. However, in the real magnetotail condition, once the ions experience non-adiabatic acceleration, they may not follow initial field lines and with the velocity in z, they may not bounce back to anywhere close to the initial field lines. This could be the situation that when the ions are getting acceleration by the Hall electric field. In this study, by using the 2D simulation, the authors investigate the ions acceleration by the Hall electric field on the dawnside of the DF and they show that the accelerated ions would assemble on the dawnside and get accelerated

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multiple times (e.g., Figure 6 and 7). In reality, this may be true for the ions with 90-degree pitch angle, but for other ions, they may leave that region after the acceleration at the first time. Therefore, in my opinion, the authors should discuss this limitation and add such warning to their conclusions.

(c) As we know, the Hall electric field is usually formed by the relative bahaviors 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 (e.g., Particle-in-Cell simulation). In this study, the Hall electric field is generated in a Hall MHD model. However, the corresponding ion kinetic behaviors in the regions with this Hall electric field are unknown. Launching test particles is equivalent to assume a state of ion kinetic behaviors (but it doesn't mean it happens in reality). To make this clear, let's take a look at the results in this manuscript. The authors show that most of the ions are drift to the dawnside of the DF and then drift tailward at the flank. This would lead to a dawnward and tailward current, which is supposed to reduce the Hall electric field self-consistently. Therefore, in my opinion, the authors should provide some discussions about such limitations.

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.

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

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

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

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?

108: “ions trajectories" → “ion trajectories"

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.

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.

122: (1) “μ_m" doesn't look correct in the second and fourth equations. (2) The “g" should be vector “**g**". (3)The $\nabla \rho_e$ term in the third and fourth equations. This should be derived from the electron pressure gradient ∇p_e. Even though the authors consider isothermal conditions, there should be a temperature factor multiplying to the $\nabla \rho_e$ term.

124: “β". There is no an explicit “β" shown before this sentence.

125: “g_x". There is no an explicit “g_x" shown before this sentence. Instead, the authors should provide information about “**g**" and how to determine the value of **g** and to make it comparable to the observations.

129: What is the value of “β" used?

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

145: “we set" should be “they set".

154-155: What are the values for ρ_L and ρ_R?

158-159: (1) “The simulation box is $2R_E$ and $1.5R_E$ in the direction of x and y". This description doesn’t look correct. The simulation results (i.e., the figures) show that there is $4R_E$ 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.

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.

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

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

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?

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

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in Figure 1. Does the asymmetry include the Hall electric field? If so, it doesn't make sense to say that the convection electric field can cancel the Hall electric field. At a location, if the Hall effect is strong, then the electric field is explained as Hall electric field; if the Hall effect is weak, the electric field is understood as convection electric field.

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.

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.

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 B_z profile look like in the launch region? It would be helpful for comparing with observations if there is a line plot of B_z as a function of x.

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? (3) Why do most of the particles even with a distance in front of the DF (the black line) move to the dawnside? Why is there no accelerated ions in front of the DF due to the reflection by the moving DF in Panel (d)-(f) (e.g., Zhou et al., 2011)? (4) In Panels (c)-(f), there are large amount of particles with very low energy at the region with x=0-0.5 and y=-0.5. How do they reach that area earlier than all those energetic particles? (5) Behind the DF, from (b) to (d), there is an obivous increase amount of particles with energy of 10keV. Is there any local acceleration happening? And why do those particles become fewer in (e) and (f)?

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.

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

226: “small" → “low"

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?

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".

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

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,...).

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?

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 E_y during this time period in Figure 6.

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

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

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.