

Author Cover Letter

Dear Editor,

We have finished revising our manuscript following the Reviewer's comments and suggestions. The revised manuscript, along with our response to the referee, are attached to this email.

Please note that in the revised manuscript, the changes made to the text are underlined for the ease of further refereeing. All of the paragraph except for 'Simulation Model' are rewritten, then we just list the paragraph rather than to say the lines in the reply. Please note that the page numbers referred to in this letter are for the revised manuscript. In addition, all new references introduced during this revision have been properly included in the reference list.

Thanks a lot for your time!

Jun Guo/Bin Yu

[Response to the Referee 1](#)

The paper focused on the study of double layers (DL) during reconnection. By PIC simulations, the authors claimed that the double layers can be created during reconnection due to the beam instability in the plasma sheet boundary layer. The isolated electrostatic waves (double layers, electron holes (EH)) have been observed in previous simulations and are believed to play a key role during reconnection. Electron holes are frequently observed by the spacecraft measurement during reconnection. Double layers are frequently observed in the ionosphere. Only recently, Ergun et al. reported the double layers in the plasma sheet in the magnetotail. But, they could not confirm the relation between the double layers and reconnection in the work. This year, Wang et al. presented the first evidence of double layers during reconnection [Wang et al., GRL 2014], and found that the double layers are moving away from X-line along the separatrix region. The double layer can accelerate charged particle effectively on its way. In this paper, the simulation domain is only about $25.6 * 12.8 d_i$ which is too small to simulate the plasma boundary layer, since the plasma sheet boundary layer denotes a huge region between the lobe region and plasma sheet in the magnetotail. In my view, the so-called 'plasma sheet boundary layer' in the text corresponds to the separatrix region during reconnection. Then, the simulation results are basically consistent with the observations [Wang et al., GRL 2013; 2014]. Based on the observations, DL and EHs are observed together. EHs are observed in the high potential side of the DL. Moreover, the DL propagates in the local thermal velocity. However, the authors found that the DL almost does not move in the simulation.

The authors need to provide a reasonable explanation.

[Thanks for pointing this out. The main reason is : "The electron beam cannot drift for a long time due the periodic boundary, which lead the DL to cannot propagate long](#)

distance”(line 32-33 on page 6). Please take a look at the parts that are added on page 6 and figure 4, 5.

According to the observations, the spatial size of the DL is about Debye length. But, it reaches the ion inertial scale in the simulation.

Thanks for pointing this out. We have carefully improved the quality of the figure 2. Please take a look at the lines 9-11 on page 5. “Besides that, a double layer with a width about $10\lambda_{De}$ lies at $x/\lambda_i \sim 3.5$, which is in the wake of a electron hole, $\lambda_{De} = v_{the}/\omega_{pe}$ is the initial electron Debye length.”

In addition, the authors claimed the DL is produced by the beam instability. Then, please show the evidence also. The language should be improved as well.

Thanks for pointing this out. Please take a look at the parts that are added on page 5-6 and the figure 2-5.

The quality of the figures should be improved. In some figures, no physical quantity can be found, like Figures 3 and 4.

Thanks for pointing this out. We have improved the quality.

Response to the Referee 2

This paper reports numerical results from 2D PIC simulations of magnetic reconnection, showing formation of double layers in regions well removed from the electron diffusion region. I find that the numerical results have been reported without giving any discussion on the physics of the formation of double layers and their subsequent evolution to triple layers. Therefore, for a reader like me the paper raises many more questions than it answers. I have some questions here for the authors to address before the paper is accepted for publication in NPG.

1. Figure 2 is an important figure in the paper, but it is made so miniscule that almost nothing can be deduced as to the structure of the unipolar electric fields and the associated charge separation that supports it. The unipolar field of a double layer necessarily implies that it is supported by two separate layers of charges, a positive and a negative charge layer. Likewise a triple layer should have its charge separation supporting the electric field. However, the density plots in Figure 2 are not very helpful. Only thing I can see from the density plots is the alternating layers of positive and negative charges separated by distances much larger than the size of the unipolar fields. So my suggestion is that the author identify one unipolar layer, and use both

horizontal and vertical scales so that charges supporting the fields and the associated phase-space structures of particles can be clearly identified.

Thanks for pointing this out. We have revised the figure and please take a look at the parts that are added on page 5 and figure 2.

2. How does the unipolar double layer originate? Is it driven by some plasma instabilities? Are Buneman or ion-acoustic modes involved in the origination process? Or do the fields emerge from the charging of density cavities by the currents along x? In presence of currents, double layers emerge when preexisting cavities charge to set up fields to accelerate electrons locally to maintain the current continuity. This was studied in a series of Vlasov simulations of double layers by Singh published in GRL and JGR in 200-2003 time frame.

Thanks for pointing this out. We have rewritten the paper and carefully studied the excitation of the DL. Please take a look at the parts that are added on page 3,5-6. The wave spectrum of parallel electric field is also added, please look at the paragraph 3 on page 5.

3. I find that the authors are not aware of literature on double layers (DLs), the earliest simulation work on current-driven double layers was published in GRL 1982. The triple layers formation with a potential dip on one end of the DL and a hump on the other end was found in simulations by Singh and Schunk published in Plasma Physics and Controlled Fusion (PPCF) in 1984. Sometimes instabilities create density cavities that charge yielding double layers. This PPCF paper describes how a triple layer emerges as a result of the DL's attempt to maintain over all charge and current balance. More recently Pottelette (Ann. Geophys., 32, 677-687, 2014, and references therein) has discussed triple layers in the auroral plasma. I suggest that the authors to consult these papers (or otherwise) to explain as to why the electric field structures with single and triple layers form in their simulations.

Thanks for pointing this out. We have rewritten the paper and mainly focused on the double layer. Please take a look at the parts that are added on page 3.

In summary I suggest that the before the authors should publish their simulation results, they provide physical explanations for what they see from the simulations. The double and triple layers should be clearly identified in terms of space charges supporting the structures. The current-driven double layers were not discovered in 2001 as implied by the references; they were found in simulations and also in lab experiments at much earlier times. The authors should cite the appropriate/relevant literature.

Thanks for pointing this out. The physical explanations about double layer have been provided in our work. Please take a look at the parts that are added on page 5-6. And also, the references are rewritten. Please take a look at the parts on page 9.

Response to the Referee 3

This paper is focused on the study of generation of double layers (DLs) and phasespace holes in magnetic reconnection regions located several ion inertial lengths away from the electron diffusion region. There are several points which appear very unclear in the present paper:

1) The quality of the Figures is very poor and almost unreadable

Thanks for pointing this out. The quality of all of the figures have been improved.

2) The authors are not aware of the literature on DLs. For instance, DLs are commonly observed in the auroral upward current region where Auroral Kilometric Radiation is generated. Tripolar structures have been recorded in these latter regions and have been interpreted in terms of trains of nested ion and electron holes (Pottelette and Treumann, Geophys. Res. Lett., Vol. 32, No. 12, 2005)

Thanks for pointing this out. We have rewritten the introduction (page 3), and new figures are added to explain the formation of the DL. Please take a look at the parts that are added on page 5-6.

3) Numerical simulations have been performed during the past decade showing that double layers are highly variable structures moving with time. (Singh et al., Geophysical Research Letters, Volume 32, 2005). The results of the present simulations show that the DLs almost do not move. Why?

Thanks for pointing this out. The propagation of DL is added in the revised paper. Please take a look at the first paragraph that are added on page 6. The reason is added on page 6, second paragraph. The main reason is : “The electron beam cannot drift for a long time due the periodic boundary, which lead the DL to cannot propagate long distance”(line 32-33 on page 6).

4) Previous simulation results by Hosino et al. (J. Geophys. Res; 106, 2001) and Prichett and Coroniti (J. Geophys. Res; 109, 2004) show that electron beams form mainly close to the separatrices. In this case strong DLs can be generated at the reconnection site. This is confirmed by the Cluster observations published by Vaivads et al. (Phys. Rev. Lett., 93, 2004)

Thanks for pointing this out. We have adopted these results. Please take a look at the second paragraph 2 that are added on page 9.

5) It would be useful to plot Figure 1b as function of the electron Debye length instead of the ion inertial length.

Thanks for pointing this out. We have changed the figure.

6) Note that the DLs reported by Ergun et al in the plasma sheet are electromagnetic structures.

Thanks for pointing this out. We have changed the sentence. Please look at the line29-30 on page 3.