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Reply on RC1

Andrei Runov et al.

Author comment on "Ion distribution functions in magnetotail reconnection: global hybrid-Vlasov simulation results" by Andrei Runov et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2020-89-AC1, 2021

We thank the Reviewer for careful reading and valuable comments.

1. Page 14, lines 11-19. The authors interpret the ion velocity shift in the x and y directions (shown in Figures 6j and 6o) as 'gyration in the increasing northward Bz'. However, this interpretation is inconsistent with the magnetic field configuration in Figure 6a, in which the magnetic field is in the earthward direction (with nearly zero Bz) at the location of the light blue virtual probe.

I would propose an alternative interpretation. Any duskward-moving ion at the virtual probe has its instantaneous gyro-center to the south of the probe, which indicates the possibility of Speiser-type meandering orbits. On the other hand, the dawnward-moving ions with gyrocenters further northward can only stay in the northern hemisphere. Therefore, the higher fluxes in the duskward rather than dawnward direction could be naturally understood by the higher density at locations closer to the neutral sheet.

In my understanding, the simulated ion distributions could be better explained by the model of Zhou et al. (2016, JGR, 'Understanding the ion distributions near the boundaries of reconnection outflow region'). As reconnection happens, the ions originally in the plasma sheet are picked up by the reconnection-associated Ey and Bz fields to move downstream away from the reconnection site. On top of this convective bulk motion, the pickup ions also keep meandering across the neutral sheet. These meandering ions must exhibit duskward and downstream directed velocities when they reach the off-equatorial boundary of the reconnection exhaust.

Reply

We agree with the Reviewer that the velocity distribution functions, observed in our simulations, may be interpreted in different ways. Particle tracing is necessary to find the unique correct answer. The normal magnetic field component is, as correctly noted by the Reviewer, small but non-zero. Thus, ions of nearly thermal energy sense the positive Bz earthward of the X-line and negative Bz tailward of the X-line and gyrate accordingly. This, to our mind, explains the mirror-symmetric hook-like distributions in Fig. 6 h and j. The duskward shift of the phase space density seen in Fig. 6 m and o is caused by the reconnection electric field in the Y direction. We think that our explanation is not significantly different from that described by Zhou et al. [2016]: the ions are moving in the reconnection-associated Ey and Bz away from the X-line and duskward. We found the paper by Zhou et al. [2016] very instructive and will add the citation.

2. Page 16, First paragraph. The authors state that 'Fermi acceleration continues during the tailward convection of the plasma'. I don't get this picture, since my understanding of the Fermi acceleration is that requires two magnetic mirrors moving towards each other. But do we have magnetic mirrors tailward of the reconnection site?

Reply

We thank the Reviewer for valuable comment. In fact, we used the term ``Fermi acceleration'' mainly as a synonym for ``parallel energization''. Our simulations indicate that the energy of field-aligned beams in ion velocity distribution functions increases during tailward progression of the reconnected flux tube. That implies a mechanism of parallel energization. Again, because we cannot trace an individual particle in the Vlasiator code, we can only speculate that this energization is caused by the flux tube shortening, i.e., the Fermi acceleration process (e.g., Baumjohann and Treumann, Basic Space Plasma Physics, Revised Edition, 2012, p.32). It is seen from the magnetic field configuration shown in Figure 2 that there are X-lines tailward of the major X-line at -13 RE. These X-lines play a role of ``magnetic mirrors''.

Technical corrections:

1. Page 10, line 15: '12.5 R_E' should be '-12.5 R_E'.

Reply

Point taken, thank you!

2. Figure 5, left panel: I don't quite understand the label of the horizontal axis, 'V_v perp B'.

Reply

It means velocity in V_perp direction, i.e., the direction of the ion bulk velocity component perpendicular to the instantaneous magnetic field in the grid cell where the vertual detector is placed. The left panel in Figure 5 shows the ion velocity distribution function cut in the plane perpendicular to the instantaneous magnetic field. The x-axis is along V-perp and the y-axis is along **V**x**B**. We will edit the Figure and add the necessary explanation to the text.