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Interactive comment on "Non-locality of the Earth's quasi-parallel bow shock: injection of thermal protons in a hybrid-Vlasov simulation" *by* Markus Battarbee et al.

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The manuscript by Battarbee et al. has discussed the proton injection issue with results obtained by global hybrid-Vlasov and test-particle simulations. I think the quality of the paper is more than enough for publication. I have a few comments and suggestions that the author might want to address before the paper should be published.

We thank the referee for the review and improvement suggestions.

The word "non-locality" is a little bit confusing. I think it is more or less similar

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to the thickness of the shock (although not necessarily the same). It might be better to add some explanation for this as it is not in the standard terminology.

We agree that coming up with terminology for a new concept is challenging, and acknowledge how, in some respects, non-locality is similar to a shock thickness. We propose that a thickness is really only valid when the shock has a well-defined upstream and downstream and a clear transition between them, e.g. in the context of the quasi-perpendicular shock when the shock profile is clear and unambiguous (well localized). In the quasi-parallel region there are challenges associated with finding the shock profile, in particular as the shock reforms, as shown in Figure 2. We will add a comparison to shock thickness to the terminology subsection in the introduction.

According to the description of the simulation parameters, the spatial resolution (228km) is larger than the ion inertial length (125 km). It may not be so bad for modelling global phenomena, but one must be careful for doing accurate simulations of collision-less shocks. In particular, since the authors followed test particle trajectories on top of their simulation results to discuss the particle interaction with the shock, the resolution can be an issue. I guess that it is not easy to perform a convergence study for this particular application in a reasonable amount of computational resources. However, the authors may caution to the readers that there is potentially a numerical resolution issue.

We appreciate the reviewer's concern regarding the ion inertial length. A convergence test is indeed unrealistically expensive to perform. We do, however, intend to investigate this issue in the future.

We would also like to note that there exists a trade-off in simulations which focus on the small scales. For example, the mesoscale reformation features shown in our Figure 2 panel a) can have spatial extents of up to 2 RE or 100 di. These arise from the interaction of the curved bow shock with incident ULF wave fronts. With a given set of simulation resources, one needs to either run a local simulation, perform system re-

scaling (e.g. Tóth et al 2017) which will negatively impact the global dynamics, or have a spatial resolution which does not resolve effects at or below ion inertial length scales. Our approach aims to investigate effects arising from the global scale. We intend to elaborate this approach and our motivation in our manuscript.

We also note that the qualitative bow shock effects and reformation seen in these simulations are in agreement with other Vlasiator simulations (see the web site,) where the 30 degree IMF simulation cell size was set to the ion inertial length. We will investigate this run in the future, but wanted to utilize the quasi-parallel IMF for this initial study.

The disagreement between the Vlasiator and test-particle results in table 1 may also arise from the same reason.

Since the test-particles and the Vlasiator distribution functions both are acted upon by fields of identical spatial resolution, we did not consider this a likely cause for the discrepancy. Test-particle fields are interpolated on the subgrid level in a linear fashion whereas the Vlasov distributions use volumetric-reconstructed fields.

The wave fields in the two runs are very different (Turc et al. 2018), resulting in differing trapping dynamics. We plan to elaborate this point of discussion accordingly.

It is no surprise to me that the non-locality is not an important factor to affect the injection as the ions have long interaction time with the shock and can travel for a long distance along the shock surface before being reflected or transmitted. The fate of the particles should be determined by the integral of electromagnetic fields as seen by them.

We agree that the electromagnetic fields are indeed the key to evaluating particle injection. As particle injection time scales are indeed significant, and close to reformation time scales, we felt it important to investigate a possible connection. There does not yet exist consensus in the field for injection and shock physics, but hopefully future studies will find convergence in our understanding of the quasi-parallel plasma shock.

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