A deep insight into the Ion Foreshock with the help of Test-particles Two-dimensional simulations” by Philippe Savoini and Bertrand Lembege

Answer to the comments of referee #2;

We thank the referee for the helpful comments. Please find below our detailed answers to each comment which are indicated in bold letter. Corrections have been directly inserted in the text in blue color for the main modification and sentences and/or parts of the sentences to be suppressed are also indicated.

Interactive comment on “A deep insight into the Ion Foreshock with the help of Test-particles Two-dimensional simulations” by Philippe Savoini and Bertrand Lembege
General comments
"A deep insight into the Ion Foreshock with the help of Test-particles Two-dimensional simulations" by Philippe Savoini and Bertrand Lembege presents a detailed analysis of 2D test-particle simulations of the ion foreshock. The simulations are tailored to- wards clarifying the role of various electric field components and the shock dynamics in the formation of the previously-reported field-aligned beam (FAB) and gyrophase- bunched (GPB) foreshock ion populations. Overall the study is well constructed but the manuscript would greatly benefit from a range of clarifications. I have a series of comments I would like to see discussed/addressed by the authors, as well as a number of suggestions for technical corrections listed below.
Specific comments

- Lines 22-24: More recent terrestrial foreshock studies could be cited too, but I leave it to the authors to decide as this does certainly not need to be exhaustive. Examples are Strumik et al 2015 (10.1002/2015GL064915); Liu et al 2017 (10.1002/2017JA024480); Otsuka et al 2018 (10.3847/1538-4357/aaa23f); Gutynska et al 2019 (10.1029/2019JA026970); Urbar et al 2019 (10.1029/2019JA026734); Turc et al 2019 (10.1029/2019GL084437). I would also like to draw the attention of the authors to the recent paper by Battarbee et al 2020 (10.5194/angeo-2019-115) which studies ion reflection at the non-stationary terrestrial bow shock, albeit in the quasi- parallel region.

The authors thanks the referee for the references. We have inserted some of them (the others are not inserted since not directly related to the main topics developed in the present paper).

- Lines 73-74 and further: It is unclear from reading this manuscript how the electric field component split is performed and which terms in the equations exactly correspond to El and Et respectively. With respect to what are "transverse" and "longitudinal" defined? I assume this would be the magnetic field but then I am confused in particular by the occurrence of parallel electric field (l. 209) and even El// (l. 236). Even though this has been treated in previous articles I would appreciate if these key elements were introduced here as well as the definition of the various electric field components is a critical piece of information for this study. I am also confused by the notations: is there a difference between components noted with a tilde, an arrow and without?

The authors have clarified these terms in section 2.
Notations: tilde refer to normalized quantities used herein (issued from the PIC simulations); arrows refer to general vector quantities; no arrow refer to general scalar quantities.

- The nomenclature regarding Fermi processes is confusing and could be made con- sistent throughout. Or, if different processes are meant, then they should be introduced in more detail.

The authors agree with the referee and have replaced "Fermi process", by "magnetic reflection" in the whole paper because all these sentences refer to the same process (i.e. magnetic reflection). The terms "Fermi type reflection" or even "Fast Fermi" have been used since an energy gain of the reflected particle (i.e. a Fermi type acceleration) is associated to this reflection process while the shock front propagates. We have now simplified and replaced most of these terms by "magnetic reflection" in the text, only in conclusion we introduce the term Fermi acceleration.

- I suggest to add "shock" to "front" on line 57 to avoid potential confusion with the fields in front/upstream of the shock.
Done

- Figures 1, 2 and 11: I would suggest to show the in-plane IMF direction and mention the out-of-plane component of the IMF for clarity.
Done, to see new panel in Figure 1 .

- Lines 63-64: Section 2 also describes the test-particle simulations. Sections 3-6 exist in the current version so this paragraph should be updated.
In order to clarify, « general » features of PIC simulations and of test particles are shortly reminded in Sections 2.1 and 2.2 respectively. All results of « HE » model are now in Section 4, including (i) specific features of « HE » model (which is new) which are detailed in Sec 4.1, and (ii) corresponding results which are collected in Sec. 4.2.

- End of section 2.1: The system size, spatial resolution and scalings are pieces of information that would be useful, in particular since they are being referred to, e.g. line 118 or Figure 9.
Done in section 2

- Section 2.2: I would also suggest to order the HE and FCE consistently throughout (abstract, introduction, figure 1, section 2.2, sections 3 and 4), maybe indeed taking first FCE and then HE every time.
We have modified the text accordingly.

- Lines 109-110: Is v_thi averaged over the box?
V_thi is just the standard deviation of a Maxwellian and we populate each box with 100 000 particles obtained randomly following this function. The number of particles is high enough to describe correctly this function.

- Figure 2 and lines 111-112: The particles are colour-coded differently in the rest of the manuscript so this mention of the colouring of particles is incorrect.
We have clarified this point in the figure caption.

- End of section 2.2. The description of the HE procedure is unclear to me. - Where is the origin of the transformation? Are only shock points transformed or everything outside of the origin? Are the resulting fields then interpolated back to the original res- olution or is the grid resolution expanding as well?
We have clarified this point.

- Lines 131-132: "Then, each front profile is selected within a same simulation time range DT..." What does this mean? Is DT ~ 4 the difference between 5.4 and 1.2 cyclotron times and there is 174 "snap- shots" taken to propagate 1 million particles each? Section 4 mentions 100 runs, also, so I guess that only the more interesting last 100 are taken?

We have clarified this point.

- Reading Section 4 lines 284-289 I understand better. So that paragraph and the one in section 2.2 should maybe be joined with an effort to clarify the scheme.

We have clarified this point.

- How long are the HE and FCE runs? - When are the test particles released in the FCE case? At a single time or over a certain period?

We use always the time T=1,2 \tau_ci as the beginning of our simulation and launch the test-particles at this single time. Then, we run the simulation until the time 5,4 \tau_ci; then we repeat this same procedure for each shock ~~wave~~ profile.

- Figure 3 and 6b: Is the colour code a density? What are the units? "Spatial distribution of percentage" is rather imprecise. It would also help the comparison if all panels were on the same colour scale, maybe with a logarithmic colour scale overall as Box 1 is very different.

The number of reflected ions is so low that the density per grid-cell can be too low to a nice representation. So, we used a gaussian interpolation which gives the relative density weight of each ion. Then, the color code (vertical bar) gives only an indication of the relative density amplitude. We have clarified the figure caption accordingly.

- Figure 4 and discussion in the text from line 164 onwards: What is the definition of the shock position in this study? As shown by Battarbee et al 2020 (10.5194/angeo- 2019-115), Figure 2 in particular, depending on the criterion taken the "position" of the shock can vary dramatically.

The paper's Battarbee simulates a quasi-parallel shock wave which has a much more complicated structure (and very different) than a quasi-perpendicular shock. In our paper, we follow a quasi-perpendicular shock (more "simple" profile) where it is easier and more precise to identify the middle of the shock front, i.e. from the ramp which is used for defining the shock front location.

- Figure 5: It might help the comparison if all plots had the same y axis, maybe with a logarithmic scale?

The authors use linear scales in Figure 4 and 5 in order to emphasize the differences between the two distinct distribution functions (i.e. one bounce and multi-bounces ion populations).

- Figure 8: It might help the comparison if all plots had the same y axis. Line 258 and the figure: are the blue lines linear fits or drawn "by hand" to illustrate?

The blue lines are only for illustration and effectively have been drawn "by hand". We have clarified this point in the figure caption of Figure 8.

- Line 261: How are the particles released at the same distance if they were released within the boxes of Figure 2?

Thanks to the referee. The sentence has been corrected.

- Line 279: I object to the use of fully self-consistent here as this is about test particles.

The simulations are "self-consistent" in terms of field evolution because fields are issued from a full self-consistent PIC simulation but the authors agree that the term fully is not the appropriate term and has been removed.

- Figure 9, lines 285 and 289: The text mentions 3 gyroperiods, the figure caption says 10. Which is correct?

10 was a mistake and has been corrected; 3 gyroperiods is correct

- Figure 10: - In the caption, the case not plotted is for Box 1, as others are shown in the left panel. There is on (b) in the figure so that can be removed from the caption too. Can the colour scale be clarified? Is it a derived phase-space density?

The "(b)" has been removed and we have added the Box_1 in the figure. This plot has been obtained as Figure 3 by using a Gaussian interpolation. Then, as for Figure 3, only an indication of the relative density amplitude in the velocity space is shown.

- It would be good to clarify also in the text: are these distributions a combination of all particles originating in one box, no matter where they ended up spatially? Could the authors illustrate/discuss the impact of this, as opposed to taking the distribution in a given spatial region, which is the more common strategy?

Let us remind that each distribution results from a combination of all particles originating from one given box (no matter where they end up spatially); we can identify it as a "pseudo local" distribution. This differs from the more common strategy based on measurements of "local" ion distributions as performed in Savoini et Lembège (2015) but which did not precise, at that time, which part of the curved shock front, the FAB and GPB ions are issued from. A deeper investigation is necessary to clarify this point and is out of scope of this paper. This point is clarified at the end of the section 5.

Technical corrections

- The title capitalisation is inconsistent.

Done

- Line 1: "test-particle" (no -s) - Line 7: on/off; detailed

done

- Line 18: This copyright statement is incompatible with the license granted at top of each page and on the discussion web page.

We have removed it

- Line 45: A large scale

done

- Line 48: "until 2 RE" or "up to 2 RE"; RE/Earth radius has not been introduced yet.

done

- Line 49: First occurrence of E and B, they could be introduced here.

We have improved the sentence

- Line 51: loses

done

- Line 72: technique
done
- Line 82 and elsewhere: Alfve□n
done
- Figure 1: time independent; in the fully consistent expansion model
done
- Line 113 & 116: boxes
done
- Line 123: a homothetic transformation
done
- Line 160: depending on
done
- Line 201: Do you mean "it cannot be necessary" or "it could be unnecessary"? I guess the latter.
done
- Line 246: stationary
done
- Figure 8: The lines are black and not blue. And both cases are switched, so black/red are respectively with and without El.
done
- Line 275: in a previous paper
done
- Line 277: correspondence
done
- Line 282: " missing
done
- Line 305: followed by
done
- Line 306: corresponds to a half gyration
done
- Line 316: taking into account
done
- Line 320 & 322: the peak amplitude
done
- Line 322: Fermi
done
- Figure 9: developed
done
- Line 330: As is well known
done
- Line 331: Lembege; "As a consequence" or "Consequently"
done
- Line 340: during which particles see (no comma); corresponds
done
- Line 341: mentioned
done
- Lines 343 and 402: discriminate
done
- Line 347: accelerates
done
- Figure 10: "(see Figure 8)" (no "to")

done
- Line 363 and 367: f1 resp. f2 and not P1, P2, I believe.
P1 and P2 have been removed from the whole paper
- Line 368: At last (?)
done
- Line 370: look at; roughly
done
- Line 384: No "Then"
done
- Line 388: dependence
done
- Line 397: associated to a
done
- Line 403: components
text have been changed
- Line 408: extra)
text has been changed
- Line 429: such as
done
- Line 432: respective
done
- Line 433: since they are being blurred
done
- Figure 11: "black" instead of "dark", maybe?

- Line 437: produced
done