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Interactive comment

Interactive comment on "A multi-fluid model of the magnetopause" *by* Roberto Manuzzo et al.

Anonymous Referee #1

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Overall appreciation

This paper discusses a new multi-fluid model of the magnetopause as well as how it can be used to initiate a time-dependent simulation to verify magnetopause stability. The model is first used to represent a specific high magnetic shear magnetopause crossing observed by MMS. A time-dependent version of the model is then used to study the time evolution of the observed configuration. The paper is well-structured, and the reasoning and conclusions are clear overall, although several aspects should be explained better. The title is rather generic and does not fully do justice to the contents: It should reflect both the fitting of an equilibrium tangential discontinuity solution to the MMS data and the study of the time-dependent evolution of the structure. I do have some problems with how the paper sketches the broader context of magnetopause models in the introduction (see below). The language is mostly clear; a list of minor suggestions and typos is given below. This work appears to be intrinsically

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Discussion paper

sound. The questions that I want to raise here mostly have to do with the presentation of the material. The paper therefore will likely be suitable for publication after revision.

Questions and remarks

The paper considers the magnetopause interface between magnetosheath and magnetospheric plasmas. It does so by distinguishing a hot and a cold ion population (magnetospheric and magnetosheath, respectively) and a neutralizing electron population. The choice of the ions suggests that one is dealing with two plasmas from two different origins. And indeed, also the electron populations on the magnetospheric and magnetosheath sides are observed to have significantly different temperatures and form two different populations. So how does the assumption of a single electron population limit the applicability of the model to the magnetopause situation? The authors should discuss this issue in some depth, for instance at lines 35-38, where they argue for a three-fluid model. The question that should be answered is: why not a four-fluid model (magnetosheath and magnetospheric electrons + magnetosheath and magnetospheric ions)?

The introduction offers a discussion of magnetopause models. This discussion should be more clear in distinguishing magnetopause models and models for plasma entry. On line 44, there is a statement regarding the electric field, which is in general not correct. Tangential discontinuity models self-consistently compute the electric field, so imposing an initial electric field will constrain, for instance, the plasma parameters (see e.g. Roth et al. 1996, https://doi.org/10.1007/BF00197842). I do not see why steady-state models with distribution functions based on conserved quantities could not be considered “multi-population models”; they actually do include multiple populations. One may view these models as representing the end result of a time evolution. This has been discussed at length by Whipple et al., 1984, https://doi.org/10.1029/JA089iA03p01508. It is not because the accessibility problem is not solved in these models that it is not considered (for instance via the boundary conditions). And in fact, this is not so much due to the fact that the models work with conserved quantities, but with the fact that they address tangential discontinuities. Note that there also have been some mixed approaches that resolve the accessibility issue (at least partially) for rotational discontinuities (such as Lee and Kan 1982 https://doi.org/10.1029/JA087iA01p00139).

Regarding existing magnetopause models, the authors paint an overly pessimistic portrait. Some magnetopause models, despite their simplifying mathematical assumptions, do go quite a long way in representing physical properties of such plasma boundaries. The equilibria they provide are not that unrealistic. Even though these models may have a number of free parameters, many of the conclusions that they arrive at are fairly robust, e.g. about boundary thickness (Grad, 1961 https://doi.org/10.1063/1.1706226), about the maximum possible tangential flow shear and the sense of magnetic field rotation (De Keyser & Roth, 1998 https://doi.org/10.1029/97JA03710), the presence of a density maximum at the high-magnetic-shear magnetopause (Hubert et al., 1998, https://doi.org/10.1029/97JA03298), etc.

The use of the model to study the time evolution of the observed structure poses a few questions that should be clarified. One of the main findings is that the observed structure is unstable and would immediately develop reconnection features. In that case, the observed structure would be out of equilibrium, so how can it then be used as a basis for examining magnetopause stability? Also, as the authors indicate, the structure would immediately lead to reconnection, i.e. one would obtain a rotational discontinuity. How probable is it then that – at the moment MMS passes this structure – it would still be of a tangential discontinuity nature, as the authors have identified earlier on?

Minor issues

14: Magnetosphere -> magnetosphere

22: Kelvin-Helmholtz -> Kelvin-Helmholtz instability

23: entering -> entry

29: It is a bit strange to cite a paper from 1998 (before the Cluster launch) to show that space plasma modelling has advanced during the Cluster era . . .

40: “Such models”: It would be illuminating to cite some examples to make clear what models are meant here.

43: Models that consider a plane tangential discontinuity do not model plasma exchange (there is no net mass transport in such models), so these do not correspond to what is mentioned on line 40.

44: When talking about tangential discontinuities: yes, the electric field can be computed self-consistently from the plasma parameters, or, conversely, given the electric field profile there are constraints on the plasma parameters.

49: “let say” -> “let’s say” or drop it altogether

49: all the other -> all the others

64: As it will be shown -> As will be shown

65: provides a -> provides

68: Please state at the beginning where this magnetopause crossing takes place – at the flanks? Near the subsolar point?

81: individuate -> distinguish

82: In this region of space, one finds both particles of magnetospheric and magnetosheath origin. In phase space, however, these particles do not occupy the same regions. Therefore, the word “mixing” might not be fully appropriate.

109 and 141: It might be useful to add a justification of the assumption of isotropic pressure and/or constant temperature for each population. In general, it is known that in a tangential discontinuity between species with isotropic Maxwellian distributions the par-

tial pressures become anisotropic inside the discontinuity layer (see, e.g. several figures with tangential discontinuity equilibria, as well as the expressions for temperature in Appendix A, in the review by Roth et al., 1996, https://doi.org/10.1007/BF00197842).

117: As written here, equation 1a and 1b assume that only electrons and singly charged ions are present; this is too restrictive if one would like to include the magnetosheath alpha particles.

122: Bad sentence construction or missing punctuation marks

Figure 2: It might be instructive to replace this plot by one that gives four curves: Ptot (constant), Pmag, Pion, and Pe. That would not only show that Pe is always much smaller, but would also illustrate how Pion and Pmag compare.

149: drop the comma

152: electrons frame -> “electron frame” or “electrons’ frame”

182-183: This is not new and may differ depending on the situation and on how one defines the position of the plasma density transition; it should not be over-emphasized. The different thicknesses and positions of the magnetic field and plasma transitions at the magnetopause have been discussed and demonstrated repeatedly from an observational point of view (e.g. De Keyser et al., 2005, https://doi.org/10.5194/angeo-23-1355-2005) but also in the context of kinetic magnetopause models (e.g. De Keyser et al., 2017, https://doi.org/10.1002/9781119216346.ch7).

190-193: As already indicated before, a temperature discrepancy is not surprising since temperature anisotropies automatically appear due to the non-Maxwellian nature of the particle distributions inside the transition layer (Roth et al. 1996 https://doi.org/10.1007/BF00197842). To immediately claim that the observed structure is out of equilibrium seems rather drastic; the authors then should have selected another magnetopause crossing example in the first place.

197: It would be good to make clear which d_i is used here. Moreover, it would be illuminating if the length scales for magnetosheath and magnetospheric ions would be expressed in terms of their own gyroradii.

202 and Figure 3d: Explain why the presence of a normal electric field component is not in disagreement with the exact plasma neutrality condition of equation 1a.

Figures 3f and 3g: How are the observed currents determined? Is that done using the curlometer? Please provide some more details either in the caption or in the main text.

Figure 3: Please also add a plot for Te (at least for the model result)

222: observe -> observes

299: the defining property -> a defining property

232: I would suggest "... that solves the time-dependent set of equations ..." since the authors earlier only used those equations with d/dt = 0.

307: bulks -> bulk quantities

308: Again, I suggest "in a time-dependent three-fluid numerical simulation"

313: known -> knowing

315-316: drop "as much"

Varia: Please be consistent with the use of "three-fluid", "three fluid", "3fluid", "2fluid" ...

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