Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-103-AC1, 2019

Annales Geophysicae Discussions
Open Access

Interactive comment on "Plasma transport into the duskside magnetopause caused by Kelvin–Helmholtz vortices in response to the northward turning of the interplanetary magnetic field observed by THEMIS" *by* Guang Qing Yan et al.

Guang Qing Yan et al.

gqyan@spaceweather.ac.cn

Received and published: 25 October 2019

Thanks you very much for your spending time evaluating our article. Your comments and critics help us to improve our understanding of the observations in this event and to find more accurate descriptions. Based on our thinking over some questions evolved in this event, we would like to response as follows. Your original comments and questions are in blue and our responses are in square brackets.

Printer-friendly version

Discussion paper

The paper reports observations of Kelvin-Helmholtz (KH) vortices by two THEMIS spacecraft (THA and THE) at the dusk magnetopause, dayside of the terminator. The periodic crossings of the magnetopause occurred following a northward turning of the interplanetary magnetic field. The identification of the vortices is based on the computation of boundary normal directions via minimum variance analysis (MVA). Interestingly, low density plasma faster than magnetosheath plasma – a common feature of KH vortices – was not observed. The spacecraft locations allow for an assessment of the evolution of the vortices: Crossing of regions with mixed magnetospheric and magnetosheath plasmas appear more/less periodic at an earlier/later stage, suggesting the transport of plasma across the magnetopause. My main criticism is related to the identification of vortices and the interpretation of observations supporting the hypothesis of plasma transport across the magnetopause. At this point, I do not think that the conclusions of the paper are sufficiently supported by the observations. Specific comments: 1) It is not convincingly shown that the magnetopause oscillations observed are actually due to the passage of magnetopause KH vortices and not, e.g., due to the passage of magnetopause surface waves that have not yet reached the non-linear stage. In this study, vortices are mainly identified by a sequence of boundary normal vectors, obtained from MVA applied to magnetic field observations (e.g., line 122+). However, MVA results can strongly depend on the selected time intervals around current sheets to which the method is applied. It would help enormously if the authors could assess the stability and reliability of the MVA results, also taking into account the eigenvalue ratios as described by Sergeev et al. (Ann. Geophys., 2006). I am doubtful about the reliability of MVA results here, because the magnetic field variations that can be analyzed are not particularly strong (see panels 3 and 7 of Figure 2).

[You are right that the MVA results strongly depend on the selected time intervals that cover the magnetopause. In this event, the IMF is strongly northward, and the observed magnetic field doesn't change much, so it could be difficult to identify the magnetopause. So, we selected the four intervals when the TH-A ion spectrum shows the magnetosheath feature (absence of the magnetospheric hot ions) to calculate the local boundary coordinates. We operated the MVA method carefully by using the high resolution magnetic field data, and by identifying the magnetopause in the ion spectrum. In diagnosing the MVA results, we also selected the better results with relative larger ratios between the eigenvalues. As you suggested above, we would like to show the details of the MVA analysis in a table, which will also be added to the revision of our article. In the MVA results (in another pdf as the supplement), it can be seen that 4 of 8 eigenvalue ratios are larger than 3, indicating the reliability of the MVA method at their corresponding crossings, even though the magnetic field doesn't change strongly. At least at these traversals, the magnetopause was deformed to the nonlinear vortices.] Furthermore, I am concerned about the identification of KH vortices in the absence of low density plasma that is faster than the magnetosheath plasma (e.g., line 141+). This feature has been used to identify vortices using single spacecraft measurements. It may also be observed without vortices being present: the passage of a surface wave should suffice. But if vortices are present, then the feature should be observable too, and I cannot find any statement in Masson and Nykyri (2016) that would suggest the opposite. So the absence of that feature indicates, in my opinion, that the oscillations are rather related to a magnetopause surface wave rather than to KH vortices. Note that rotations in the bulk velocity, magnetic field deviations, and distortions of the magnetopause can also result from magnetopause surface waves (e.g., line 205).

[We agree that the high-speed low-density feature is one of the typical characteristics of the K-H vortices and very useful in diagnosing the K-H vortices in single spacecraft measurements. It was a surprise to us that the high-speed low-density feature did not appear in the Ni-Vm plot in this event. We used to estimate the magnetosheath velocity by drawing a horizontal line that is close to most of the magnetosheath intervals shown in panel 4 of figure 2. The horizontal line was at the velocity of about 180 km/s. Now, we re-estimate the magnetosheath velocity by averaging the TH-A measurements during the four magnetosheath intervals, with the more accurate velocity of about 134 km/s in the magnetosheath. Based on the new estimation, the high-speed low-density feature can be seen in the Ni-Vm plot, with more data points distributed in blue box (see the revised figure 5 below). The high-speed low-density feature can support the K-H vortices in this event. Furthermore, the linear surface waves could not explain the fine structure of the observed first perturbation in TH-E observations, show in the additional figure below, which we are further working on, with new results of the micro-physical process to transport solar wind into magnetosphere within the K-H vortices in another article. The double peaks in the ion measurements can be caused either by second traversal of the non-linear K-H vortex or by the secondary substructure of the vortex. More details of the plasma transport in the K-H vortex will be revealed in another article in preparation.] 2) It is not convincingly shown that a significant and unambiguous plasma transport took place across the magnetopause (e.g., lines 211, 214). This main conclusion of the paper is inferred from observation of less periodic features seen by THE in comparison to THA, the former being located further down the tail from the latter. I would at least expect some further discussion on how this strong conclusion can be drawn from the observations (e.g., by putting the results into the context of prior observations or simulations). However, also the observations themselves are not consistent over the presented time interval: As can be seen in Figure 2, THA sees more periodic magnetopause oscillations before 22:40 UT, as discussed in the paper. After 22:40, THE sees very periodic oscillations and THA observations are "more dispersed" (e.g., between 22:44 and 22:51). Following the argument in the manuscript, plasmas should have unmixed while vortices moved from THA to THE during this period of time. [Thank you for your comments that can further our thinking over some questions in this event. Above all, word "unambiguous" in conclusion has been deleted so that it is not so strong. The coexistence of hot and cold ions is one of direct feature of the solar wind transport into magnetosphere, as clearly displayed in Geotail observations by Fujimoto et. al. (1998) and in Cluster observations by Hasegawa et. al. (2004). In this event, the coexistence of hot and cold ions was firstly noted near the periodically oscillating magnetopause. Furthermore, we used the enhancement of hot electron flux as the indicator of the LLBL, and set up the more critical criteria to diagnose the coexistence, and hence to display the transport regions, as marked by

Printer-friendly version

Discussion paper

the green bars at the bottom of panel 6 and black bars at the bottom of panel 10 in figure 2. Compared with the possible pre-existing LLBL before the perturbations, the coexistence of hot and cold ions shows the fresh entering of cold ions into the LLBL. The evidence of the plasma transport is clearly shown in this event. By comparing the green bars and the black bars, it can be found that the transport regions in TH-A observations appears more periodic but those in TH-E observations more dispersed. The difference between the features of transport regions at upstream TH-A and downstream TH-E implies the plasma transport significantly occurred and evolved during the tailward propagation, along with the collapse of the vortices, leading to a kind of turbulence state, as illustrated in previous simulations (Nakamura et al., 2004; Matsumoto & Hoshino, 2004). You are right that TH-A observed very clearly periodic motions of magnetopause during the 34 minutes except UT 22:46-22:50 TH-E observed relatively much more dispersed spectrum during the interval but 5 clear periods of oscillations appeared again during UT 22:40-22:48. However, it seems true that on the whole the spectrum observed at TH-E is much more turbulent than the periodic spectrum at TH-A. Such characteristics imply the collapse of the vortices and the evolution leading to turbulence state. In previous simulations (Nakamura et al., 2004; Matsumoto & Hoshino, 2004), the vortices collapse and transport solar wind into magnetosphere, after that, new vortices may be generated at the recovered magnetopause. The 5 oscillations during UT 22:40-22:48 at downstream TH-E can by explained as newly formed vortices. If you agree with the above discussion, it will be added to the text to enrich the understanding of observations in this event. Thank you for all your comments, critics and suggestions that help us to improve the article.] 3) It is not convincingly shown that there was no pre-existing (low-latitude) boundary layer (LLBL), consisting of a mixture of magnetosheath and magnetospheric plasmas. This mixture is used as a synonym to plasma transport across the magnetopause in the paper (line 164), supposedly starting with the northward turning of the IMF. But a LLBL might have been present at the magnetopause even before the oscillations started. To confirm this or rule it out, we would need spacecraft observations across the magnetopause near the

THEMIS positions before the event. However, such observations do not seem to be available, and both THA and THE were probably too far away from the magnetopause to observe a pre-existing LLBL. During the event, as the surface waves went by, the magnetopause moved periodically closer to the spacecraft so that they were able to enter the LLBL, as stated in line 204. [Thank you for your comments that have pushed us to think over the question further. It is true that we need observations of another spacecraft nearby across the magnetopause to confirm or rule out the possible pre-existing denser layer. We used to trying the MMS conjunctions but the four-spacecraft stellar were not located near THEMIS. From the observations in this event, we only know that neither of the 2 spacecraft of THEMIS near the magnetopause observed the pre-existing denser layer before the K-H waves (surface waves according to your comments). As you pointed out, "a LLBL might have been present at the magnetopause even before the oscillations started". To tell the truth, we cannot confirm the absence of the pre-existing denser layer before the perturbations. So the description that "there is no pre-existing denser layer to facilitate the instability" has been deleted. Thank you for your reminding that the word "mixture" was inappropriately used as a synonym to plasma transport across the magnetopause. Mixture is a state of two components in plasma, such as the plasma in LLBL, while transport is a process of the transfer of solar wind into the magnetosphere. The LLBL is a result or consequence of the solar wind transport into magnetosphere. In this event, the most prominent characteristics are the periodic oscillations of the magnetopause, and the coexistence of hot and cold ions, with more emphasis on the transport process. So we are using the word "transport" and "coexistence" to describe the event. The "mixture region" in the caption of figure 6 was also replaced by "coexistence region" to avoid misleading.] 4) I do not know what the authors exactly mean by "field-line stretching" (e.g., lines 22, 118) and how such a behavior would be reflected or identifiable in single spacecraft ion velocity or magnetic field time series. [Thank you for your suggestions. We used to describe the deformation of the magnetopause accompanied by the field line stretching as illustrated by Hasegawa et. al. (2004), the magnetic field was disturbed at the low latitude region.

Actually, the magnetopause deformation can cause the magnetic deviations, and the deviations can be available in both linear surface waves and nonlinear vortices, as you mentioned in your comments. In order to avoid misleading or misunderstanding, the “field line stretching” has been deleted for more accurate description.]

Minor comments on figures: - Figure 1 conveys very little information. It may be sufficient to keep only the x-y-plot. [Thanks for your suggestion. We revised the figure by taking only the X-Y plot indicating the location near the magnetopause and the Y-Z plot indicating the low-latitude region.] - It may be helpful for the reader to state the meaning of the green and black bars in Figure 2 (below panels 6 and 10) in the caption. [Thank you for such a reminding. The description of the green and black bars has been added to the caption of figure 2.] - I cannot see any reason for the inverted time line in Figure 3. Please state a clear reason or display the data in the conventional way, with time moving forward to the right. [In this event, it was at the duskside of magnetopause, we displayed the vectors of the velocity and magnetic field perturbations not only in plots but also in arrowed lines (black lines in panels 3-6), with the scales of the magnitudes on the right side of each panel. The directions of M and N components correspond to the leftward and downward directions respectively, viewing from the Z direction. The data on the right side occur earlier than those on the left side, earlier data should be propagated more tailward to the rightside. We used the reverted time line (as Hasegawa et al. (2004) used in their publication in Nature) just in order to show the time sequence from right to left. The illustrations of Vm, Vn, ΔBm, ΔBn have been added to the scales on the right side of panels 3-6.]

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-103/angeo-2019-103-AC1-supplement.pdf

Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-103, 2019.

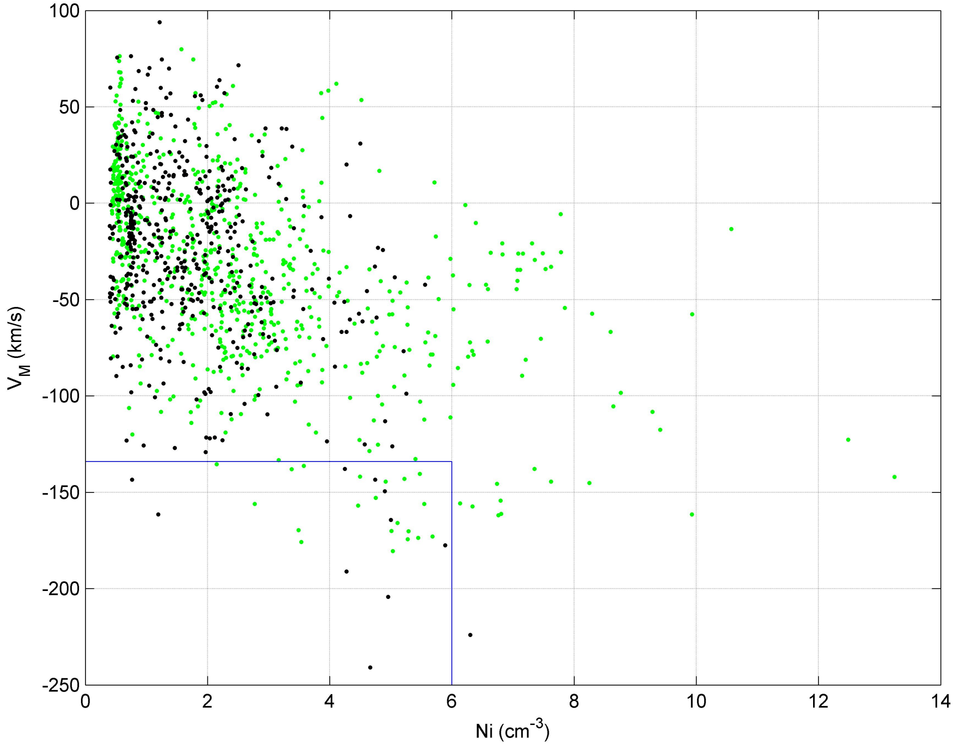

Fig. 1. Figure 5. The observed velocity along the tailward direction versus the ion density. Green dots are from TH-A observations and black dots from TH-E observations. The blue lines mark the high-speed and

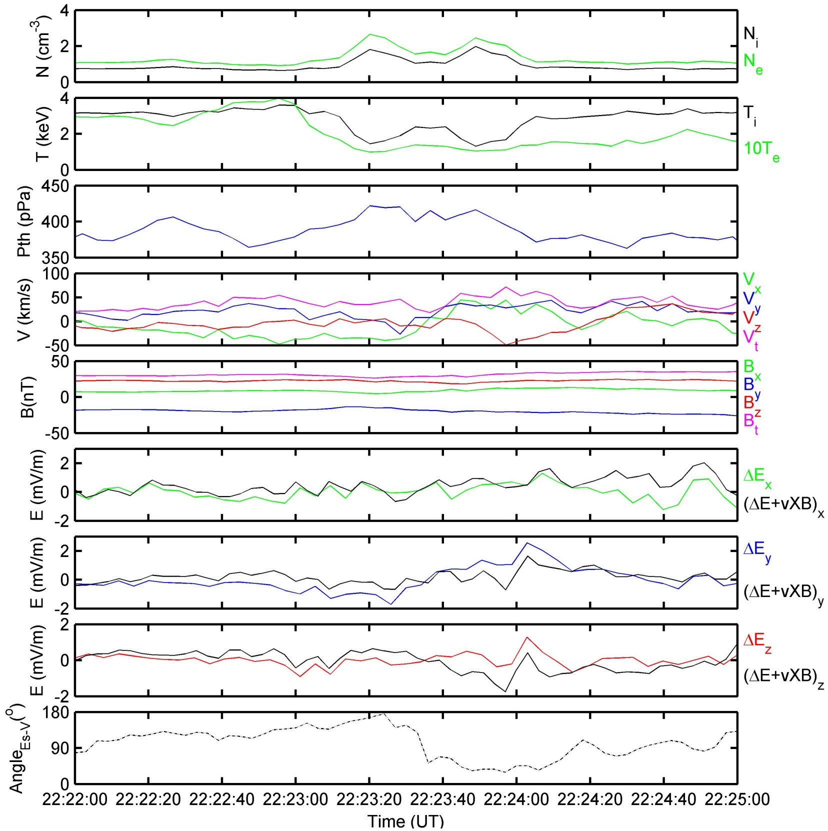

Fig. 2. Additional figure, which is not enclosed in this article, to show the double peaks in TH-E plasma observations. The linear surface waves could not explain the double peaks.

Interactive comment

Printer-friendly version

Discussion paper

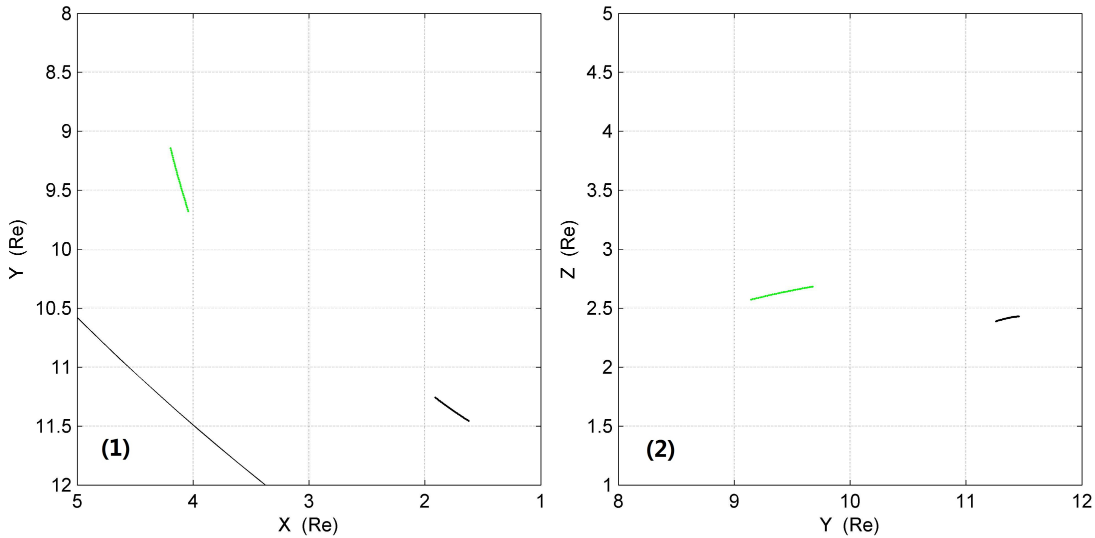

Fig. 3. Figure 1. The orbits and positions of TH-A (green) and TH-E (black) during the interval of interest UT 22:20 $\sim$ UT 22:54. The position data are expressed in GSM coordinates.

Printer-friendly version

Discussion paper