Ionospheric density depletions around crustal fields at Mars and their connection to ion frictional heating

GENERAL COMMENTS

The authors investigate how density depletions in the ionosphere of Mars are correlated with the crustal fields and show how said depletions might be connected to ion frictional heating. The paper is well written and presents different aspects of the topic taking advantage of the available MAVEN observations from several instruments. The authors define certain parameters which then use to quantify the correlation between the crustal fields and the ionospheric depletions and their connection to ion frictional heating. The plots are clear and help the reader to understand the main points of the paper. There are some parts in the paper though that need further clarification.

SPECIFIC COMMENTS

2. Methodology, Event Selection, and Data Sources:

- Could the authors perhaps add a short paragraph about the instruments used in the paper? For example, what each instrument measures and such.
- Do the authors survey the whole LPW data from 2015 to 2022 or a part of it? For example, only dayside, what range of SZAs and altitudes? or have the authors used some other specific criteria? How many orbits do the authors check? Maybe the authors could be more specific here.
- Line 79: Could the authors demonstrate an identification example plot from the data like they show in Figure 1. Perhaps the authors could just add to Fig. 1 a density profile and some lines on the plots indicating where the event starts and ends to show how they identify the depletions. That would also help the readers later when the authors describe the various Δn parameters and refer to measurements near the boundaries or out of the boundaries.
- How do the authors search for the depletions? Do they first check the time series and if there is something they also check the profile? They check both time series and profiles for each orbit and compare? I would like to see a more detailed description of the identification process which would also fit nicely with the recommendation above about demonstrating the identification in a plot.
- When the authors calculate the proximity parameter ζ, and use the magnetic filed measurements they should also state the coordinate system they use, for example that the $B_{i, sc}$ x, y, z components are in the MSO system.
- Lines 89-90: ''In deriving Equation 1, effects of generic similarities between time series (constant arrays), singularities, and absolute strength of the fields are also considered'' → Could the authors elaborate on that? Perhaps they could explain these effects in more detail and how they are considered.

- Line 95: ''The minimum accepted quality flag in LPW data is 50'' → Could the authors elaborate on that? What does that mean exactly? It would be useful for readers who are not familiar with LPW data too.
- Line 100: ''We down select...''→ Could the authors elaborate on that? Events with $\zeta <$ 5 are selected but out of how many and why? Why do they authors choose $\zeta < 5$? Arbitrarily? Can the authors provide a plot like a histogram/distribution with all the ζ measurements and the crustal fields values to show why they choose 5? Or a plot that shows ζ as a function of the strength of the crustal fields?
- Lines 101-102: ''...visual inspection of several events...''→ how many events are identified in total? How many were inspected?
- Lines 101-102:''...the total number of events... a reasonable sample size''→ In my opinion this is not the right reason to select the right value for ζ. If there were fewer events for example, would the authors select events with much higher ζ – and thus farther from crustal fields – just to have a sufficient number to do statistics?
- It would be helpful for the readers if the authors could somehow present either by giving some numbers or with a plot as previously suggested, what happens at $\zeta = 5$. How strong the crustal fields are in the identified depletions for $\zeta = 5$, and what happens below and above this limit.
- Line 102:''We find 242 events in LPW data set.'' → Total events? Events with zeta<5? Also, in what locations the authors see the depletions? Perhaps the authors can include a crustal field map with the locations of the depletions and/or altitude and SZAs of the events.
- Figure 1→ The authors could add the altitude in km and the SZA as well below the figure.

3. Observations:

- Lines 112-113: An example here would be helpful. If the authors could add vertical lines for example in Figure 1 with the minimum density and the limits of the hole (left and right) it would be easier to demonstrate exactly how they calculate the depth.
- The authors now use spherical coordinates for the magnetic field. For the ζ calculation MSO was used. Maybe the authors could emphasize that and also elaborate a little on why spherical coordinates are more appropriate for their analysis.
- Line 120: ''The depletion depth does not depend on ζ ''→ If I understand correctly, this means that the depletion depth does not depend on the crustal fields. Would be interesting to compare depletions farther from the crustal fields to see if you get the same depth distribution.
- Line 121: ''...color coded by the total strength of the magnetic field.'' → Do the authors mean the total strength measured or modelled (crustal fields) ?
- Line 121-123: ''Events with the highest magnetic...appear at low ζ...mostly above 0.1''→ I am a little confused with that statement. Events with high magnetic field strength would also be the events where crustal fields dominate so by definition ζ should be low. Also the fact that the depletion depth is larger for those events does it mean that there is after all a correlation between crustal fields and depletion depth? Because the previous statement says that the depth does not depend on ζ.

- Figure 3 – Perhaps the authors could give a more detailed description of the plot. Since the same format is used in Figure 4 as well.
- Line 133: No correlation between ζ and altitude. So no correlation of the crustal fields and the altitude? Perhaps the authors could emphasize that in the paper.
- Lines 141-143: ''some depletion events…or near the boundaries'' → Perhaps the authors could show some examples here of the different categories. Isn't there a third category with disappearing suprathermal electrons? The increase or decrease of the suprathermal electrons is given by the same parameter $\Delta n_{e,S}$ but it is not stated clearly here. (If there is a word and/or figure limit for the paper the authors can ignore my suggestions about including more plots)
- Line 145: ''…measured density outside the depletion.''→ Do the authors use a mean/median or just the first measurement outside the depletion? Could the authors state this in the text? This would be much easier to show if the authors included vertical lines in Figure 1 showing where the depletion starts and ends.
- Line 146: Same as the previous comment, now for $\Delta n_{e,S}$.
- Line 153: ''…discussed in previous studies of depletions…''→ Could the authors give some examples and include the corresponding references?
- Lines 151-154: The six events for which there is no enhancement in the suprathermal electrons, where are they located? Is their ζ larger? Are these events also included in Figure 5b and if so where exactly?
- Lines 158-159: ''…many events at low altitudes…crustal fields are stronger.''→ Perhaps this statement can be quantified somehow and the authors could provide some numbers to support it because I see also intermediate altitudes with high $\Delta n_{e,C}$ values.
- Lines 161-164: Perhaps the authors could elaborate on their results of Figure 6? Would it be useful if a ''depth'' is also defined for the ion depletions and be compared with the electron ones? Also why are there a few cases for which there is an enhancement in the ion densities? Where are these events observed?
- Line 188: ''…three events exhibit a reduction in ion temperatures…''→ It is difficult to see the three events in the Figure. A vertical dashed line at zero may help.
- Lines 189-190: ''Since we investigate…available temperature data decreases.'' → I am confused with that sentence. I am not sure what the authors want to say here.
- There are several statements in the paper about the number of events and how many events for different kinds of measurements are available. I was confused in the end. How many events were used for the analysis of the depletions, the suprathermal electrons and the ion temperatures?
- Figure 5: Would it be useful to color-code the altitude in Figure 5a as well?
- Figure 7: Could the authors add more lines below the plot, like the altitude and the SZA for example?

5. Conclusion:

- Lines 243-245: Could the authors elaborate in the main text (observations section) on how the parameters they use (the differences of ionospheric densities) minimize the effects mentioned here?

TECHNICAL CORRECTIONS

Abstract:

- Line 12: ''…the crustal magnetic field are…''→ ''…the crustal magnetic fields are…''

1. Introduction:

- Line 54: ''…depletions on the nigh side of Mars…''→''…depletions on the night side of Mars…''
- Line 54: ''…(Cao et al. 2022) argued…''→''…Cao et al. 2022 argued…''
- Line 57:''…cooccurrence…''→''…co-occurrence…''

2. Methodology, Event Selection, and Data Sources:

- Line 77: ''…measurements between 2015 up to 2022 for ionospheric… → ''…measurements between 2015 and 2022 for ionospheric..'' or ''…measurements from 2015 up to 2022 for ionospheric…''
- Lines 78-79: This sentence seems a little strange.

3. Observations:

- Line 125: ''In Figures 3 we discuss...''→ ''In Figure 3 we show…''
- Line 125-126: the verb is missing
- Line 144:''…in cold or bulk electr on density''→ ''…in cold or bulk electron density''
- Line 162: ''…with increase in $\Delta n_{e,s}$…''→''…with increase in $\Delta n_{e,C}$…''

4. Discussion:

- Line 206: ''…which atomic oxygens becomes…''→''…which atomic oxygen becomes…''
- Line 209: ''…relevant reactions area listed below''→ ''…relevant reactions are listed below'' maybe also say reactions and reaction rates are listed below?
- Line 230: ''…removes caused…'' ?

Figures:

- In different parts of the paper the authors refer to the panels of the figures sometimes as Panel a, for example and sometimes as Panel (a). Perhaps they could use just one way.
- Figure 1: The lines below the plot of X, Y, Z are not aligned with the numbers.
- Figure 1: The y ticks labels on the first panel are too small compared with the other panels.
- Figure 5: The letters a) and b) above the panels are in different positions.
- Figure 6: ''Excluded in the figure are…''$\rightarrow$''Eight depletion events… are excluded from the figure.''