

Reviewer 1:

The paper presents interesting and new observations of the cold ion population in the plasmasphere. I have a few comments and questions that should be addressed before publication.

Answer: We thank the reviewer for carefully reading our manuscript and the helpful comments.

General: The motivation for this study is very well laid out, but the results are not put into context enough. Simply comparing with old measurements is not sufficient, I would like to see some discussion on how the new findings from this study influence our general understanding of the plasmasphere and how knowledge of plasmasphere composition can advance our understanding of the wider field.

Answer:

1. The main conclusion of the paper concerning the Earth plasmasphere is that we can confirm the existence of a strong molecular heavy ion population at a distance of 2.1 R_E from Earth. Since there has been only one comparable observation (Craven, 1985) by a special setting of the RIMS instrument on DE-1 this is a very important confirmation which may lead to new observation campaigns and simulations in the future.
2. The main achievement of the paper is a more technical one: we show for the first time that the spacecraft potential can be used as a mass filter by its effect on the angular distribution of the observed ion flux. To our knowledge this has never been described before.

L. 25 is this height or radius?

Answer: measured from Earth center, corrected.

L. 26 a reference for the temperature and density would be good

Answer: added reference to Van Allen Probe observations (Genestreti et al., 2017).

l. 50 I think the reader would appreciate a short summary of the contents of that paper. Why is the cold ion population important for the magnetospheric dynamics?

Answer: the major conclusions of Delzanno et al.(2021) are now reported.

l. 60 wrong parentheses on citation

Answer: thanks, corrected.

Fig.1 Some of the text is overlapping in the figure. It is also unclear which direction the moon is moving.

Answer: The figure has been edited and better annotated.

Fig. 4 I cannot read the labels in this figure, they are too small and the contrast especially in the blue is poor.

Answer: The figure has been edited and better annotated.

Fig. 8 The figure should really be inverted to be printer friendly. I also recommend against the use of the rainbow colour scale, it is not colour blind friendly and the hues also do not have a linear brightness. Viridis is usually a good alternative. The same goes for the colorbar in the other

figures.

Answer: We have edited figures 8 and 9 and changed the color scale.

L. 137 - 139 *"It is interesting..." Is this statement to confirm that the spacecraft potential measured by RPWI is reasonable?*

Answer: We added: This shows that the values observed for JUICE are not uncommon - though the potential value depends on the material properties of spacecraft surfaces.

L. 142 *"the asymmetric shape of the spacecraft potential" this may need some more explanation. Why is it asymmetric, how does that influence the detection direction?*

Answer: we added: by the fact that for a small Debye length the shape of the spacecraft potential follows the spacecraft structure \citep{zeroual2026}.

l. 158 *have you calculated the errors? Are they small compared to the overall counts?*

Answer: We added now statistical error bars to Figures 10 and 11. These errors are later propagated to the values in equations 2 and 3.

l. 166 *so would you characterise your values as a lower limit?*

Answer: we added: Further below we try to include these effects and derive much higher density values.

Fig. 11 *Could you add error bars to the counts here? It would help to affirm the detection*

Answer: Error bars were added.

l. 255 *How did you get to 30%? is this from the numbers in equation 3 and the RPWI density?*

Answer: We now refer to equation 3 and correct the value to 25%.

l. 271-273 *So could you explain at least the 15eV peak by a B parallel beam? Because the other peaks seemed less conclusive in the discussion in section 3. If you can attribute the 15eV peak to accelerated ions, then do you have sufficient evidence for the other heavy ions? What velocity would be necessary to achieve that signature with a B parallel beam? I think this one sentence needs more careful discussion.*

Answer: We added now a discussion at lines 304ff. The essential argument for our explanation of the observed spectra is the agreement with the predicted effect of the spacecraft potential. The magnetic field acts on ions on much larger scales and does not produce distributions with the observed sharp cut-offs.

Conclusion: I find it difficult to understand what your main conclusions are. The overall density is from RPWI and the 30% figure has not been explained sufficiently in the text. The 15eV peak could be due to magnetic field. I think there is sufficient new knowledge here, but a more precise conclusion would improve the paper. You say further laboratory calibration is needed, but why was it not included in this publication?

Answer: The 30% has now been corrected with reference to the calculation in equation 3. The possible magnetic field effect has been further discussed. On additional tests of channeltrons at low voltage in laboratory: This requires construction of a specific test setup by an engineering team. Since our engineering team is currently overloaded with preparations for the RAMSES mission we

can only schedule such tests after instrument delivery for RAMSES next year. In the mean time the post-acceleration voltage of PEP JEI onboard has been increased to -500V. We expect new observations of the plasmasphere with this setting during the next Earth swing-by of JUICE.

Reviewer 2:

Summary

This manuscript presents observations of cold plasmaspheric ions obtained during the first Earth gravity assist of the JUICE spacecraft on 20 August 2024. The authors analyze measurements from the PEP/JEI and RPWI instruments during a passage through the Earth's plasmasphere and report signatures for multiple ion species, including H^+ , He^+ , O^+ , and possibly heavier molecular ions such as N_2^+ , NO^+ , and O_2^+ . The interpretation is supported by a simplified model of ion trajectories in the spacecraft potential and by calculations of the JEI sensor response. The manuscript presents potentially unique observations, as direct measurements of cold plasmaspheric ion composition are scarce and the possibility of detecting heavy molecular ions in the outer plasmasphere is particularly intriguing. The paper is generally well written, contains a comprehensive overview of previous observations, and documents the observation geometry and instrumental setup. The main strength of the manuscript is that it goes beyond the presentation of a single Earth flyby dataset and demonstrates a potentially important new analysis capability of the JEI instrument, namely the possibility of using JEI measurements to infer the composition of cold ion populations. This aspect is likely to be particularly relevant for future JUICE observations of the exospheres of the Jovian moons. The manuscript is generally well written from both a grammatical and stylistic point of view, and the presentation is mostly clear and easy to follow. Still, several concerns regarding the interpretation of the observations and the robustness of the conclusions are discussed below. In general, I consider the manuscript suitable for publication, provided that the authors carefully address the comments below, which may help make the presented conclusions more robust and better substantiated.

Answer: We thank the reviewer for the detailed and insightful comments.

General comments and suggestions

1/ The manuscript states in the Conclusions that negative spacecraft potentials have also been observed in the Jovian plasma environment and are predicted for JUICE, which supports the relevance of the present analysis for future observations near the moons of Jupiter. However, this point is only mentioned very briefly. Since one of the main motivations of the manuscript is the potential application of the JEI technique to ion composition measurements in the exospheres of the Jovian moons, I encourage the authors to discuss this connection in somewhat greater detail. In particular, it would be helpful to clarify under what plasma conditions similar negative spacecraft potentials are expected for JUICE in the Jovian system and how comparable those conditions are to the Earth plasmasphere case presented here.

Answer: We now added a discussion of the applicability for Jovian plasma environments based on the simulations by Bochet et al., 2023.

2/ A substantial part of the interpretation presented in the manuscript relies on the assumed spacecraft potential structure around JUICE and on its effect on the observed ion energies and angular distributions. However, this aspect is not discussed in sufficient detail. Are there already dedicated estimates or numerical simulations of the spacecraft potential structure around JUICE available (possibly as part of Zeroual et al., 2026)? If so, I think it would be very valuable to include or discuss them in the manuscript in more detail, as they would provide a stronger physical basis for the assumed potential structure and for the interpretation of the JEI observations.

Answer: We now added a discussion (line 148ff) of the calculated potential which is less negative than the observed potential.

3/ The interpretation of the broad spectrum observed at theta about 33 deg as evidence for multiple ion populations and/or heavier ions is intriguing. However, the manuscript does not provide sufficient statistical context to assess how representative this spectrum is of the entire plasmasphere crossing. How frequently are such broad spectra observed? Are they consistently associated with similar energies and elevation angles, or do they represent only isolated events? Providing at least a brief overview of the occurrence frequency of these broad spectral features would considerably strengthen the interpretation. It would also help to better assess the reliability and robustness of the proposed method for inferring ion composition from JEI observations. Otherwise, it remains difficult to judge whether the inferred heavy-ion populations represent a persistent characteristic of the observed plasmasphere or are based primarily on a few selected examples.

Answer: We now analyze the number of spectra of this type observed during the passage in line 186ff: 28 out of 108. We further discuss the significance in lines 295ff.

4/ I found the definition and transformation of the relevant coordinate systems a bit difficult to follow in the current manuscript. In particular, a more explicit description of the conversion between GSE and the spacecraft reference frame (SRF) during the analyzed time interval would be very helpful, as it is not straightforward to infer this from a comparison of Figs. 4 and 5 alone. In this context, it could be useful either to plot the magnetic-field direction also in Fig. 5, or to express it explicitly in the SRF. At present, the magnetic-field information is only given in GSE coordinates in Fig. 6, while only limited information on the SRF geometry and the polar angle definition is provided in the text around line 100, with only later complementary information given in the discussion. Related to this, I found the term “polar inclination angle” somewhat confusing. The term polar angle usually refers to an angle measured from a reference axis (or normal), whereas inclination is more commonly understood as an angle measured relative to a plane. I would therefore suggest using simply polar angle (or alternatively defining the term more explicitly if a different convention is intended).

Answer: We added now the relation between SRF and GSM/GSE to the caption of Figure 5. At the time of writing the magnetic field measured by the JUICE magnetometers is not available in offset corrected form. Thus our analysis uses the Tsyganenko model field. This field vector is rotated in the SRF in Figure 6. We now also included the vector in Figure 5.

5/ I wonder whether the order of subsections 2.1 and 2.2 could be reversed. In my view, the discussion of the observing geometry would be easier to follow after first providing a clearer description of the JEI instrument itself. In addition, the current subsection 2.1 refers to other PEP sensors (e.g., NIM and JNA), which are not introduced elsewhere in the manuscript. It might therefore be useful to add a short general paragraph on the PEP instrument suite to the

instrumentation subsection, in order to place JEI in context and make the discussion more self-contained.

Answer: We now changed the order and describe the PEP sensor suite in line 92ff.

Particular comments and suggestions

lines 9-10 - But this response -> This response...

Answer: corrected

line 12 - Still we can already conclude... -> We can conclude...

Answer: replaced by Nevertheless...

line 20 - Jovian Ion and Electron -> Jovian Electron and Ion

Answer: corrected

line 24 - The subsection title "The Earth plasmasphere" could be removed.

Answer: removed.

line 32-33 - This instrument -> RIMS instrument (?)

Answer: clarified.

line 33 - mass 32 -> units amu/q?

Answer: clarified.

line 48 - plasmaspheric temperature -> plasmaspheric ion temperature (?)

Answer: yes, corrected.

line 131/Figure 8 - Are these energy spectra integrated over all elevations?

Answer: Yes, a temporal average of 4.6s has been applied which spans the time interval of 8 elevation steps.

line 140-142 - The manuscript invokes a possible asymmetry of the spacecraft potential structure as an explanation of the observed discrepancy between the direction of the peak counts and the spacecraft velocity vector. However, under the plasmaspheric conditions considered here, the Debye length is only of the order of centimeters, i.e. much smaller than the characteristic spacecraft dimensions. Could the authors better justify the expected magnitude and spatial extent of such asymmetries, and discuss whether they are sufficient to explain the observed ion deflections? It may also be worth commenting on whether magnetic-field effects could contribute to this discrepancy, or whether they can be safely neglected compared to the electrostatic deflection by the spacecraft sheath (ref. to paragraph lines 270+).

Answer: We have now rephrased the sentence and refer to the later discussion.

lines 145-147 - The sentence beginning "While an acceleration by the spacecraft potential..." is difficult to follow. At this point in the manuscript, the higher-energy spectral peaks have not yet been introduced, so the reader does not yet know what features are being referred. I suggest first introducing these additional spectral peaks explicitly and only then discussing their possible origin and significance. Furthermore, the manuscript states that the higher-energy spectral peaks were

“unexpected”. However, in the presence of multiple ion species corotating with Earth, ions with different mass-to-charge ratios should naturally appear at different energies after acceleration by the spacecraft potential. Could the authors clarify in what sense these peaks were unexpected and whether they can be explained solely by the combination of corotation velocity and spacecraft acceleration?

Answer: we now rephrased the sentence to describe how the discovery of the effect was made. The corotation velocity is small compared to the spacecraft velocity as described in Figure 6.

line 166 - The rather low density can also be attributed to the spacecraft potential - see the later comment on equation B6.

Answer: We have added a respective sentence.

line 167 - The apparent double peak in the spectrum at theta of 14.4 deg may indicate a bimodal distribution, although simple statistical fluctuations or instrumental effects should also be considered.

Answer: We now include the statistical error in the figures.

line 181-185 - In Fig. 12, ions are launched at a distance of 50 cm from the surface, while the Debye length estimated in the manuscript is only about 8 cm. Starting the ions at 50 cm may be reasonable if this is intended to represent a field-free region outside the sheath. However, the assumed linear potential drop from 0 V at 50 cm to -5 V at the surface appears difficult to reconcile with the quoted Debye length, since most of the potential variation should occur within a few Debye lengths. I suggest that the authors better justify the choice of the 50 cm scale length and discuss how sensitive the simulated ion deflections are to the assumed sheath thickness and potential profile. Although the SIMION method is well established, an appropriate reference could be added.

Answer: we now make clear that Figure 12 is only for illustration but not for quantitative estimation. We added a reference to SIMION.

line 185-190 - Both equations (for $\tan(\theta)$ and E/q) appear to contain dimensional inconsistencies, likely due to typographical errors. Please check them carefully.

Answer: we thank the reviewer and had discovered an error in the equation already earlier. The equation has now been corrected and the derivation is explained.

line 192-193 - "Since the initial polar inclination angle is about 45 deg the expected inclination angle decreases with increasing potential." The sentence reads somewhat awkwardly. I suggest rephrasing it and briefly clarifying the underlying geometry and physical reasoning.

Answer: The sentence has been edited.

Figure 1 and 2 - The figures appear to use the same color-scale limits but show different colors in the plasmasphere interval. Could the authors explain this?

Answer: Figure 1 has now been corrected and better annotated. The effect was caused by using different temporal averages.

Figure 5 - A white background might improve the readability of the figure, in particular the visibility of the plotted directions and annotations and the SC structures.

Answer: The figure has been edited and annotation improved. The background and lighting is set by

the Cosmographia software to agree with real onboard or remote camera observations.

Table 1 - It could be completed by a row for $V_p = -6.5$ V, as reported by RPWI measurements, for comparison.

Answer: we added a row with $V_p = -6.5$ V.

Eq. B6 - There appears to be a typo in the expression: E^2 should likely read E . More importantly, this expression is only valid if the initial ion kinetic energy is much larger than $q|V_p|$, which is not the case for the present observations. The correct form would require a substitution $E \rightarrow E + qV_p$ and would therefore introduce another fitting parameter, V_p . If Eq. B6 is fitted directly to uncorrected spectra while the spacecraft potential is effectively absorbed into the fitted mean energy, the angular term remains inconsistent because it should include the correction for the potential energy as well. This may bias the fitted density, especially in the present case where the spacecraft potential is comparable to or larger than the intrinsic ion energy.

Answer: Thank you for this comment. Indeed the appendix B did not discuss the effect of the potential – though it was included in the derivation of Figures 14 and 15. We now included an explicit analysis of the potential effect in appendix B. To our knowledge this is the first time that the potential effect is explicitly calculated for a drifting Maxwellian velocity distribution (apart from the discussion in Mott-Smith, 1926.) Also the typo in equation B6 was corrected.