Plasma leakage through the magnetospheric boundaries of Jupiter and Saturn

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Abstract

Jupiter and Saturn are the largest magnetized planets in our solar system. Their magnetospheres, which form in the interaction between the solar wind plasmas (protons and alphas) and their intrinsic magnetic field, are characterized by the existence of a plasma disk. The multi-species plasmas (heavy ions) created deep inside the magnetosphere of Jupiter and Saturn is transported radially, redistributed throughout the whole magnetosphere, before to be lost down tail or at the boundaries of the magnetosphere.

Based on the work of Thomsen et al. [1] at Saturn, the goal of this study is to analyse ion composition data, using statistical methods, and answer the following question: **Do magnetospheric species leak through magnetopause and bow shock boundaries?**

The NASA Juno mission, with its JADE-I particle spectrometer, is ideally suitable for this type of analysis. The NASA/ESA Cassini mission, with its CAPS particle spectrometer, in orbit around Saturn during 13 years, provided a large datasets of bow shock and magnetopause crossings which have also been largely unexplored to date.

Crossings catalog of the bow shock and magnetopause allow us to distinguish three regions: magnetosphere, magnetosheath, and foreshock/ solar wind. We analyse ion composition data and look at the Time Of Flight (TOF) - Energy spectrograms to identify the different species within the three regions.

In this study, we present the preliminary results of this statistical analysis and describe the spectrograms for Jupiter and Saturn. We **show traces of suprathermal ions in the magnetosheath** that may originate from the magnetosphere. This could indicate leakage at the magnetopause through phenomena that remains to be identified.

1. Methodology: Orbits / boundary crossings

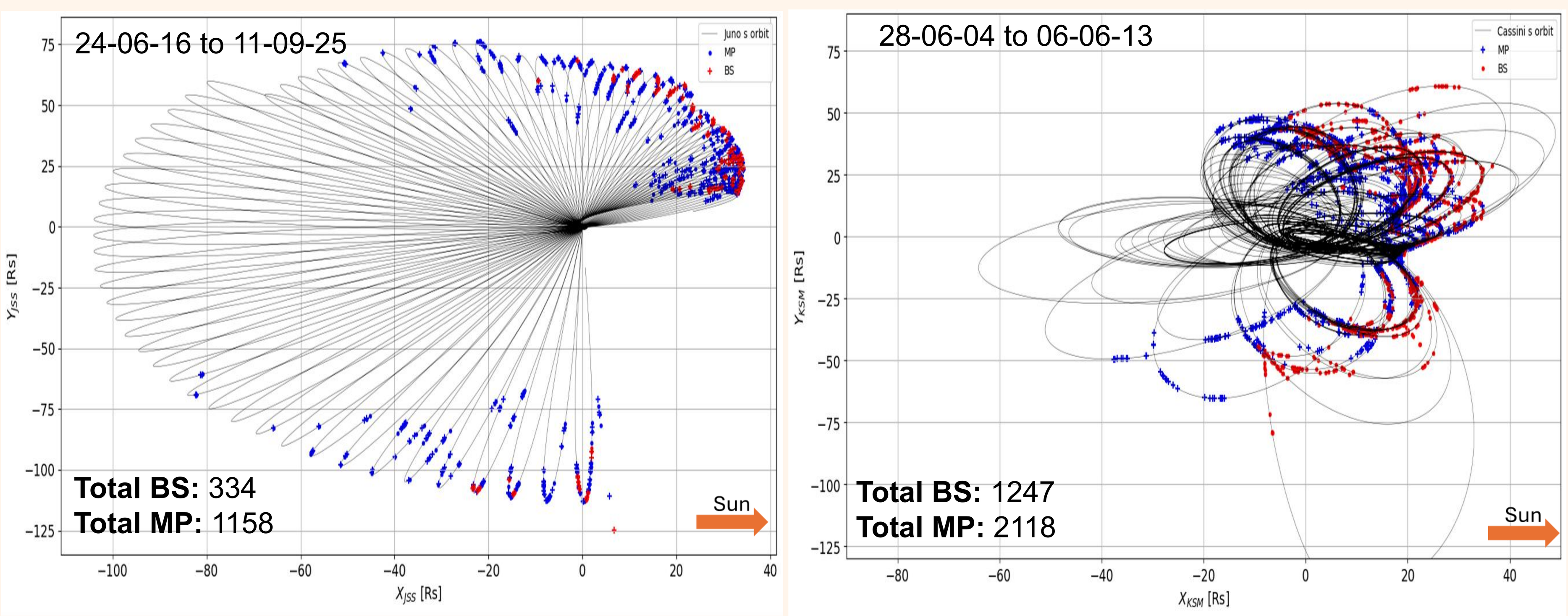


Figure 1: Orbit on the XY plane. Left: Juno's orbit. Right: Cassini's orbit. Dots and crosses represents the crossing of a boundary, based on the catalog of Fuller et al [2] for Juno and Jackman [3] for Cassini

- Jupiter's boundaries model from Rutala (2025) for Jupiter, and Kanani (2010) (magnetopause), Went (2011) (bow shock) for Saturn, are work in progress and will be presented in a later time.
- Juno's data from the Jupiter's crossing catalog from Fuller et al [2] are the only ones we worked with in this study.

2. Methodology: Ion composition data used

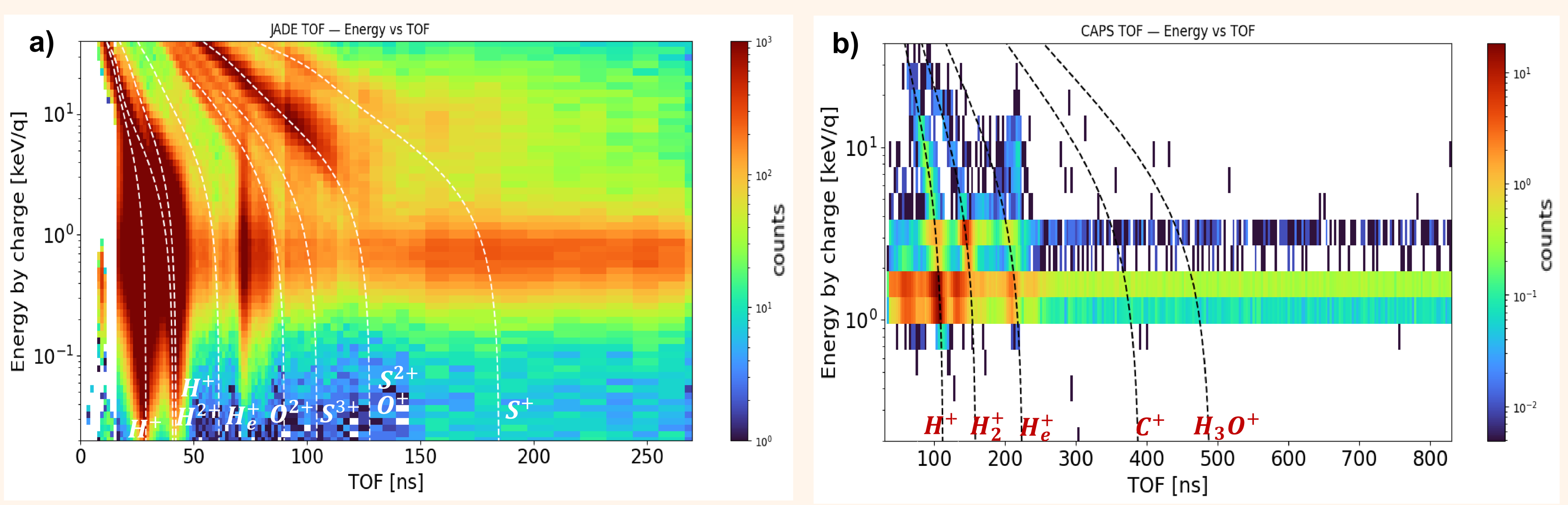


Figure 2: a) JADE-I TOF vs Energy for the 18-03-2023. b) CAPS TOF vs Energy for the 10-09-2005 18h - 24h. Dashed lines represent different species expected in the vicinity of the planets and in the solar wind ([4] for JADE-I, [5] for CAPS).

- The difference between species are determined by the ratio velocity/mass.
- There can be coincidences between multiple species, as for S^{2+} and O^{+}, that cannot be differentiated by the instrument.
- Broad streak across all TOF values at ~1 keV are due to coincidences between protons and alpha particles within the instrument [1].

3. Methodology: Orbital coverage (local time, latitude)

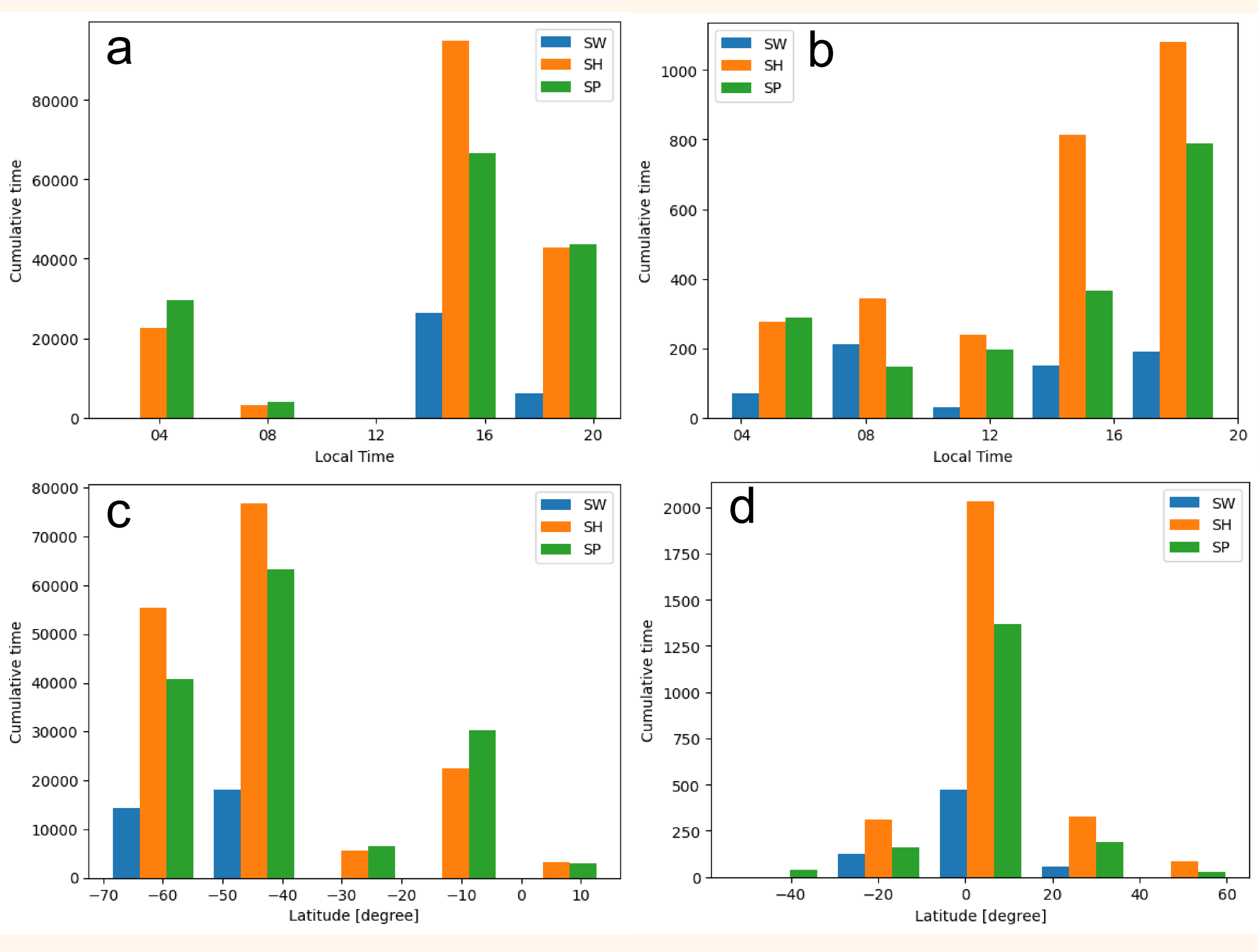


Figure 3: Localization of spacecraft by local time (a, b) and latitude (c,d) for **Juno** (**left**) and **Cassini** (**right**)

- We use the catalogs of boundaries to distinguish 3 different regions of space: Solar Wind (SW), Magnetosheath (SH) and Magnetosphere (SP) .

a: Juno's orbits are mostly around dusk and dawn, as seen in Figure 3 (left).

b: Cassini's orbits are distributed almost equally from 04h to 20h local time for the solar wind region. The presence in the magnetosphere and magnetosheath is in 16h – 20h local time essentially.

c: Juno have polar orbits (high latitude).

d: Cassini's orbits are mostly on the ecliptic plane.

Results 1: Statistical analysis

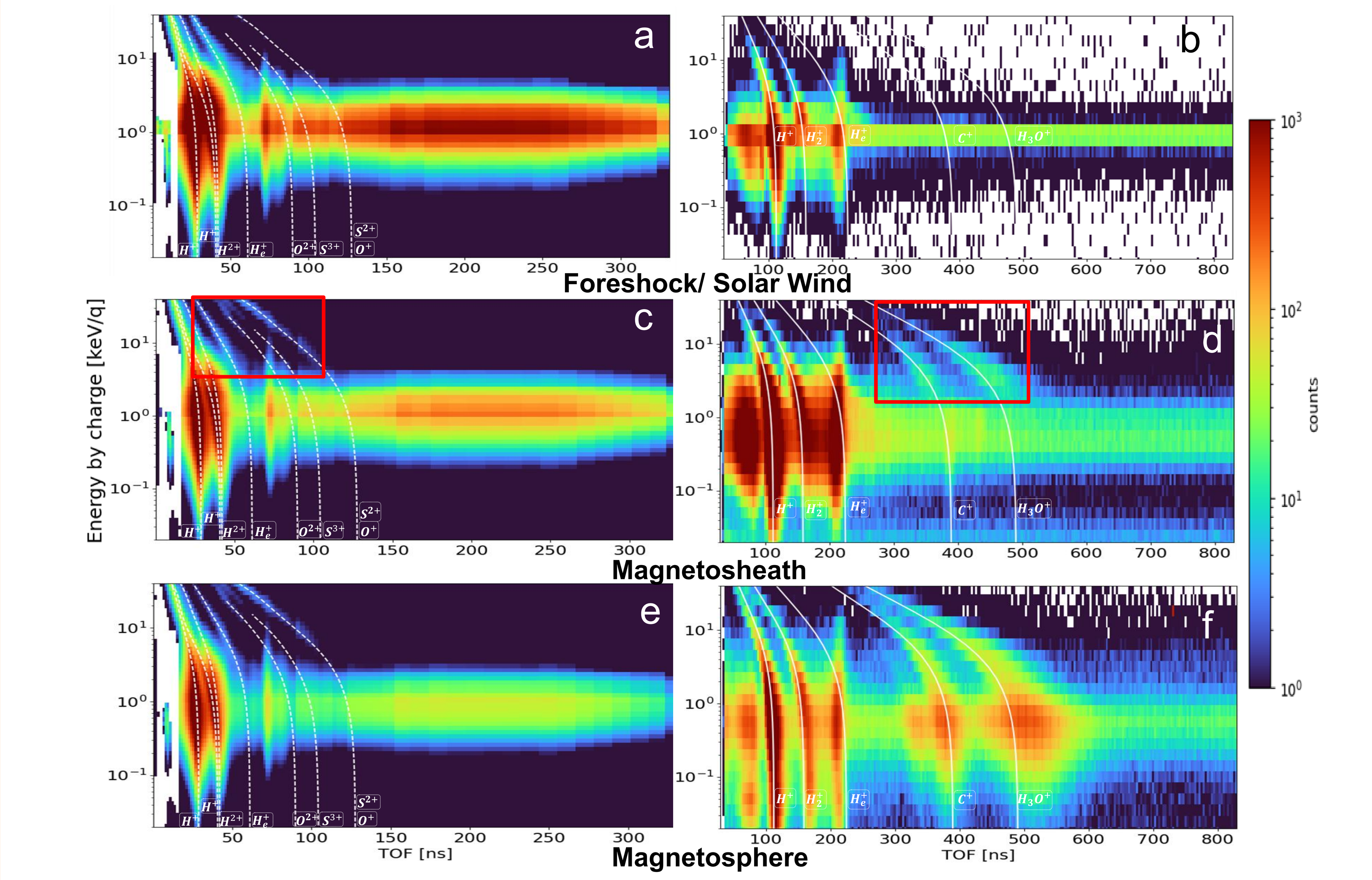
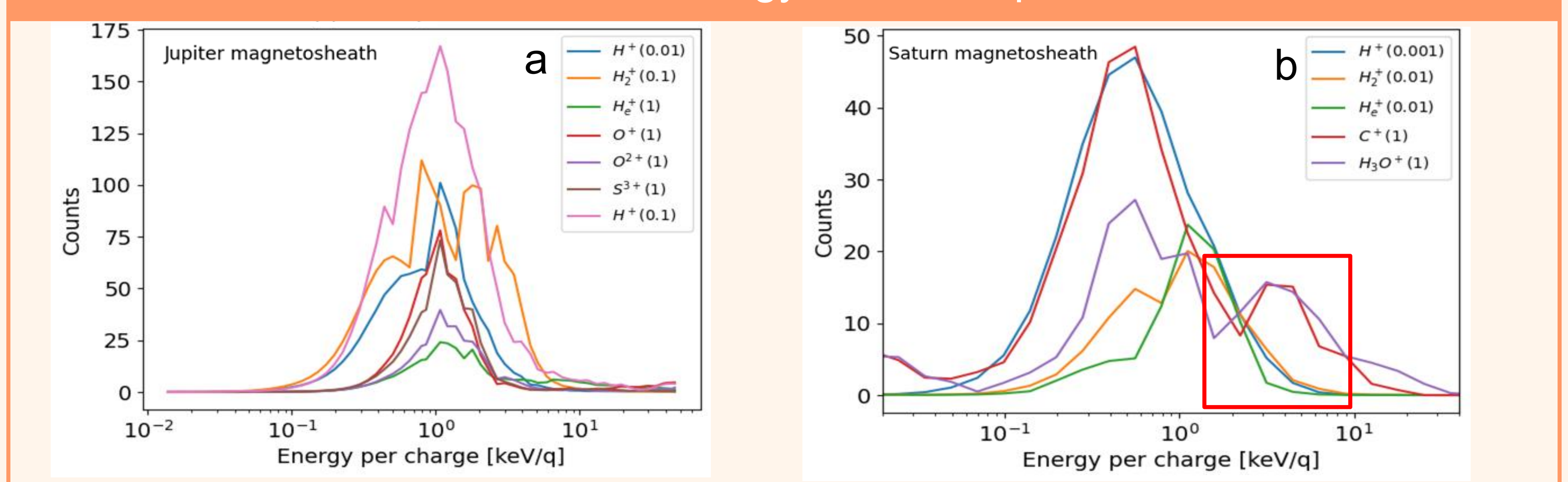


Figure 4: Spectrogram of stacked data for each region (Solar Wind, Magnetosheath, Magnetosphere) for **Jupiter** (**left**) and **Saturn** (**right**)

- For Jupiter spectrograms, the total count have been divided by half the number of stacked files, to prevent saturation.
- **No signs of heavy ions in Foreshock/ Solar wind region** (a,b). This implies no leakage through the bow shock boundary.
- We identify the **presence of suprathermal (~10 keV) heavy ions in the magnetosheath** (c,d) (red rectangle). This suggest heavy ions leakage at the magnetopause.

n.b.: The straight line around TOF 70 (JADE-I) and TOF 200 (CAPS) origine is still to be determined, but it is instrument related.

5. Results 2: Energy vs counts per ions



- The peak around 1 keV could be in part noise (as seen in Figure 4), due to coincident protons and alphas on the detector [1].
- This make the detection of non-suprathermal heavy ions harder than for suprathermal ones.
- The suprathermal heavy ions in the Saturn's magnetosheath (**b**) (red rectangle) are not present in the magnetosphere (**c**).

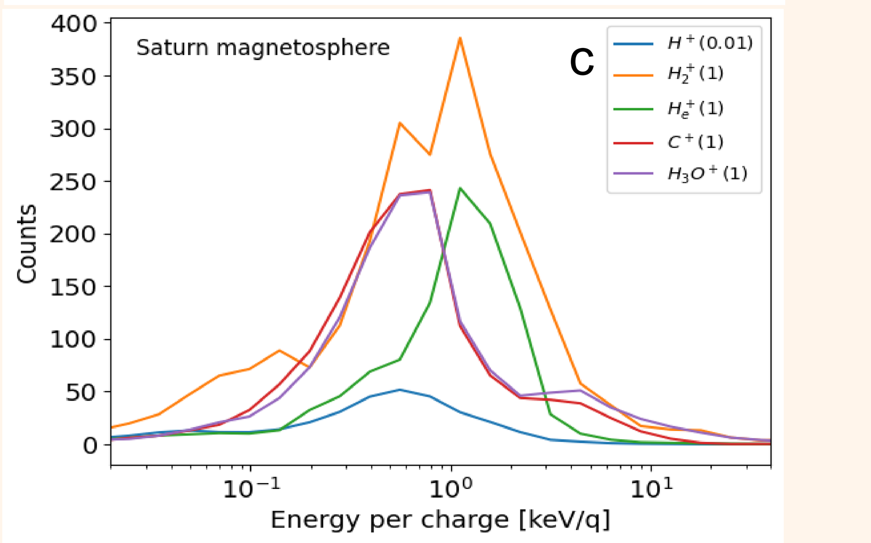


Figure 5: E/Q vs Counts of species within the magnetosheath (a,b), and magnetosphere (c), for **Jupiter** (**left**) and **Saturn** (**right**)

6. Conclusions and Perspectives

- We confirmed the presence of suprathermal heavy ions in Jupiter and Saturn's magnetosheath.
- Detection of non-suprathermal heavy ions will requires to subtract coincident protons and alphas at ~1keV.
- Next step of the study could help to locate regions in the magnetosphere where this phenomenon is the most present through the data organization in local time/ latitude bins.
- Once we obtain a detailed map of the leakage, we will look at the possible phenomena responsible for these leakages (Kelvin-Helmholtz instabilities, magnetic reconnections).

[1] Thomsen et al. (2007), *Assessment of the magnetospheric contribution to the suprathermal ions in Saturn's foreshock region*, Journal of Geophysical Research, VOL. 112

[2] Fuller et al (2026), *Magnetopause and Bow Shock boundary crossings at Jupiter* [Data set]. Zenodo. https://doi.org/10.5281/zenodo.18749969

[3] Jackman (2019), *Survey is Saturn's Magnetopause and Bow Shock positions over the entire Cassini mission*, , Journal of Geophysical Research, VOL. 124

[4] Kim et al (2020), *Method to derive ion properties from Juno JADE including abundance estimates for O+ and S2+*. Journal of Geophysical Research, VOL. 125

[5] Young et al (2004), *CASSINI Plasma spectrometer investigation*, Space Science Reviews 114

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