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Saturn's ionosphere: Electron density altitude profiles and ring shadowing effects from the Cassini Grand Finale.

L. Z. Hadid (1), M. W. Morooka (1), J-E. Wahlund (1), A. M. Persoon (2), D. J. Andrews (1), O. Shebanits (3), W. M. Farrell (4), W. S. Kurth (2), N. J. T. Edberg (1), E. Vigren (1), L. Moore (5), M. M. Heddman (6), T. E. Cravens (7), A. F. Nagy (8), A. I. Eriksson (1)
(1) Swedish Institute of Space Physics, Uppsala, Sweden, (2) Department of Physics and Astronomy, University of Iowa, USA, (3) Space and Atmospheric Physics, Imperial College, UK, (4) NASA/Goddard Space Flight Center, Maryland, USA, (5) Center for Space Physics, Boston University, USA, (6) Department of Physics, University of Idaho, USA, (7) Department of Physics and Astronomy, University of Kansas, USA, (8) Climate and Space Sciences and Engineering, University of Michigan, USA. (lina.hadid@irfu.se)

Abstract

Using the latest *in-situ* measurements of the Langmuir probe (LP) part of the Radio & Plasma Wave Science (RPWS) instrument package onboard the Cassini spacecraft, we analyse the electron density altitude profiles of all the proximal orbits from the Cassini Grand Finale.
Firstly, we study the electron density (n_e) altitude (h) profile by comparing the northern and the southern hemispheres. We construct an average ionospheric profile in the northern hemisphere and show a layered structure. Similar layers were observed during the Final Plunge of Cassini, where the main ionospheric peak is crossed at $\sim$ 1550 km altitude [1]. Secondly, from the ring shadow signatures on the total ion current, we reproduce the A and B ring boundaries and confirm some of their optical properties. Furthermore, observed variable response of the ionosphere to the B ring shadow implies different proton production rate and plasma transport from the C-D rings [2].

1. Electron density altitude profile model

We show in Figure 1-a the consecutive h, n_e profiles of all the proximal orbits measured by the LP and for some cases estimated from the plasma wave frequency characteristics of the RPWS investigation. The black line represents the averaged topside ionospheric profile up to 5500 km. As one can see, it exhibits a layered structure with distinct regions denoted by **P** ($h > 4000\,\mathrm{km}$), **D** ($2200\,\mathrm{km} \lesssim h \lesssim 4000\,\mathrm{km}$) and **C** ($h < 2200\,\mathrm{km}$). Region **P**, which we interpret as the inner part of the plasmasphere, is characterized by near-constant n_e values with respect to altitude before it starts to increase around $4500\,\mathrm{km}$. Region **D** represents a diffusive equilibrium region, it is highly variable and structured. Region **C**, which is a chemical equilibrium layer, is more stable and regular and dominated by heavy ions [3, 4].

In Figure 1-b, we present the "Final Plunge" orbit. One can clearly relate the three

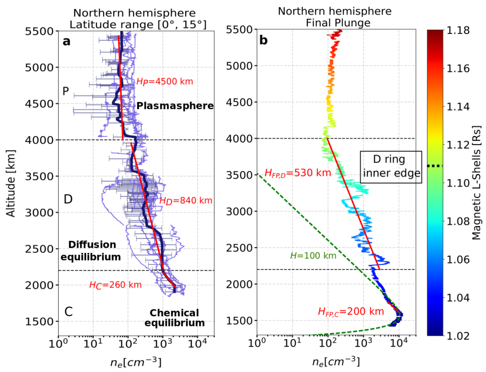

Figure 1: (a) The averaged h, n_e profile (dark blue curve) over all the proximal orbits (purple curves) in the northern hemisphere. (b) The h, n_e profile of the Final Plunge orbit. The color code shows the corresponding magnetic L-Shell values.

different ionospheric regions highlighted in the averaged profile. The color code corresponds to the magnetic L-Shell values and shows that region **D** maps well inside the inner edge of the D ring. This implies that the observed irregularities density profiles in layer **D** not connected to features in the rings. The red lines represent the estimation of the plasma scale height by fitting with an exponential curve for each of the regions **P**, **D** and **C**. Last but not least, during the Final Plunge orbit the LP have revealed a density peak of $\sim 1.5 \times 10^4$ cm^{-3} around 1550 km, which we interpret as the “main peak” of the Kronian ionosphere.

2. A and B ring shadowing effects

As Saturn’s northern hemisphere experienced summer during the Grand Finale, the planet’s northern dayside hemisphere and its rings were fully illuminated by the sun. However the southern hemisphere was partly obscured because of the shadows cast by the A and B rings, which are opaque to the Extreme Ultraviolet (EUV) solar radiation. As a consequence, this caused noticeable decrease in the amount of ionization in the southern portion of the ionosphere which was clearly observed by a decrease in the total DC ion current ($I_{DC,tot}$) collected by the LP (blue curve in Figure 2).

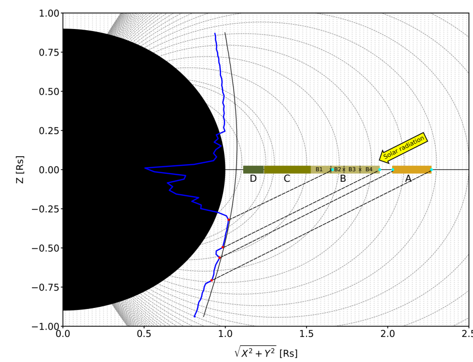

Figure 2: Example of one proximal orbit (Rev 276) passing between Saturn (in black) and the rings (green rectangles). The blue curve represents the total DC current for negative bias voltage projected on the orbit.

As is shown in Figure 2, considering a solar elevation angle of $26.3°$, we project the outbound slant passes (larger for local times away from noon) onto the ring plane, and compare the observed projected boundaries of the shadowed regions (blue dots) with the ring boundaries.

In Figure 3 we summarize the distances from Saturn of the observed starting and ending points of the shadows compared with the A and B ring boundaries (black dashed lines). The color code represents the total DC current. Based on the current values, we consider the LP in complete shadow when the

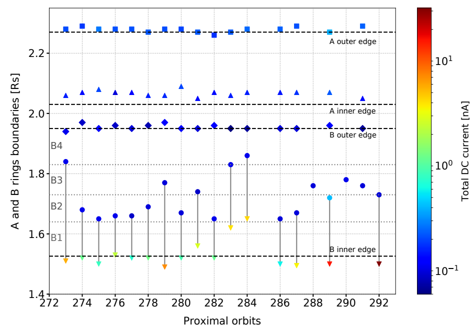

Figure 3: Summary of the observed inner and outer edges of the shadows casted by the A (triangle and square respectively) and the B rings (circle and diamonds respectively). The dashed black lines represents the inner and outer boundaries of the A and B rings.

collected current is below the photoelectron level (< 0.7 nA) or around the noise level (0.1 nA). As one can see, the observed edges of the shadow cast by the A ring (squares and upward triangles) match very well with its boundaries. Regarding the B ring, the observed outer edges of the shadow (Diamonds) match the outer edge of the ring consistently from one flyby to another. However this is not the case for the inner edges of the shadow (circles), they are neither uniform nor matching the B ring inner boundary. For each orbit, we represent by a downward triangle the distance at which $I_{DC,tot}$ starts to decrease and by a circle the distance at which the LP is shadowed by the B ring ($I_{DC,tot} \sim 0.1$ nA). For most the flybys, $I_{DC,tot}$ starts to decrease around the inner edge of the B ring.

The observed variations in the starting point of the B ring shadow around 4000 km, for distances outside $1.65\,R_s$, could be related to the changes of the proton production rate resulting in different responses of the molecular hydrogen to the shadowing effect. Furthermore, plasma transport processes from/to the rings could also inhibit the shadowing signature from the B ring.

3. Summary

This study has provided detailed analysis of the Kronien topside ionosphere by evidencing a layered structure with at least a diffusive and chemical equilibrium regions. Moreover, based on the observed A and B ring shadows we could study the reponses of the ionospheric plasma in the absence of the sunlight as an ionization source.

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