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Re-analysis of the Cassini RPWS/LP data in Titan's ionosphere: electron density and temperature of four cold electron populations

A. Chatain[1,2], J.-E. Wahlund[3], O. Shebanits[3,4], L. Z. Hadid[2,3], A. Eriksson[3], M. Morooka[3], N. J. T. Edberg[3], N. Carrasco[1] and O. Guaitella[2]

[1] Université Paris-Saclay, UVSQ, CNRS, LATMOS, Guyancourt, France.

[2] LPP, Ecole polytechnique, Sorbonne Université, université Paris-sud, CNRS, Palaiseau, France.

[3] Swedish Institute of Space Physics, Uppsala, Sweden.

[4] Imperial College London, UK.

(audrey.chatain@latmos.ipsl.fr)

The Cassini Langmuir Probe (LP) data acquired in the ionosphere of Titan are re-analysed to finely study the electron behaviour in the birthplace of Titan's aerosols (900-1200 km). The detailed analysis of the complete Cassini LP dataset below 1200 km (57 flybys) shows the systematic detection of 2 to 4 electron populations, with reproducible characteristics depending on altitude and solar illumination. Their densities and temperatures are deduced from the Orbital Motion Limited theory. Statistical correlations with other quantities measured by Cassini are investigated. We finally discuss the origins of the detected populations, one being possibly emitted by aerosols.

1- Introduction

The Cassini mission discovered that Titan's ionosphere is the birthplace of the solid orange aerosols surrounding Titan [1]. It is an ionized environment (plasma) hosting a complex ion chemistry [2]. The aerosols are formed and certainly eroded [3] in this environment. They are likely to interact strongly with the plasma species (i.e. electrons, ions, radicals and excited species): the ionosphere of Titan is a 'dusty plasma' below ~1100 km [4], [5]. Besides, models of the ionosphere do not match well measurements below 1100 km [6]. Recent works [7]–[9] showed the necessity to take negative ions and aerosols into account in the models.

The present work aims to finely analyse the behaviour of electrons in the aerosols-containing region of the ionosphere (~900-1200 km) sounded at 57 occasions by the Cassini Langmuir Probe (LP), part of the Radio and Plasma Wave Science (RPWS) package.

2- Re-analysis using 2 to 4 electron contributions

The current collected by the Langmuir probe in the conditions of the ionosphere of Titan can be modelled according to three hypotheses: (1) the electron velocity distributions are considered Maxwellians; (2) in the case where the probe repels electrons, the current collected can be given by the Orbital Motion Limited (OML) theory [10], [11]; (3) in the case where the probe attracts electrons, the current is fitted using the Sheath Limited theory [12].

To obtain a satisfactory fitting, we show the necessity of using 2 to 4 electron populations (named P_1, P_2, P_3 and P_4) at different potentials [13]. We observe (see Figure 1) that the second derivative of the current is useful to deduce the number of electron populations detected on a measurement and gives an idea of their relative proportions. Indeed, d^2I/dU^2 is physically related to the electron energy distribution functions (EEDF) through the Druyvesteyn method [14].

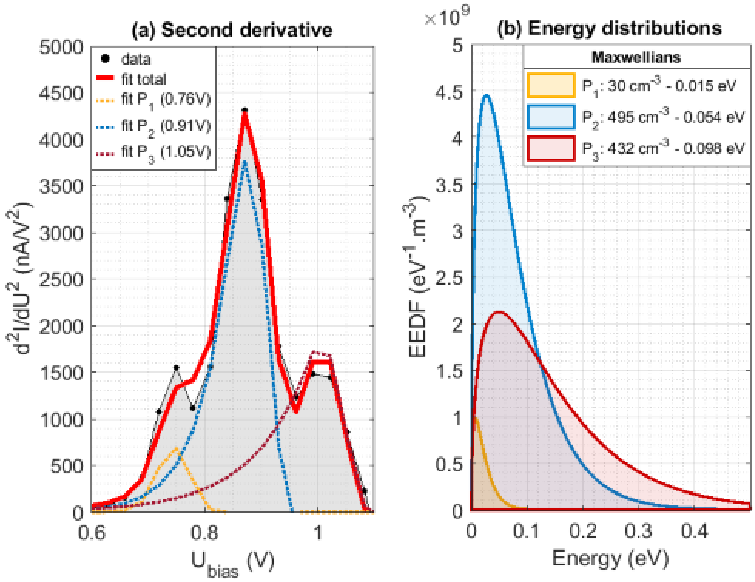

Fig 1. Detection of 3 electron populations in the RPWS/LP data acquired on flyby T50 at an altitude of 1125 km.

3- Populations: strong dependence with SZA and altitude

The visualisation of electron populations with d^2I/dU^2 is used in Figure 2 to show the variations of the populations with altitude and solar illumination. Populations P_1 and P_2 are always present, contrarily to P_3 and P_4. Due to their low density and low potential, P_1 electrons are suspected to be photo-electrons [10] or secondary electrons emitted on the probe stick. P_3 electrons are only absent on the far nightside, while P_4 electrons are detected only on dayside, and below the altitude of 1200 km. For this reason, they are suspected to be related to aerosols or heavy negative ions that appear below 1200 km.

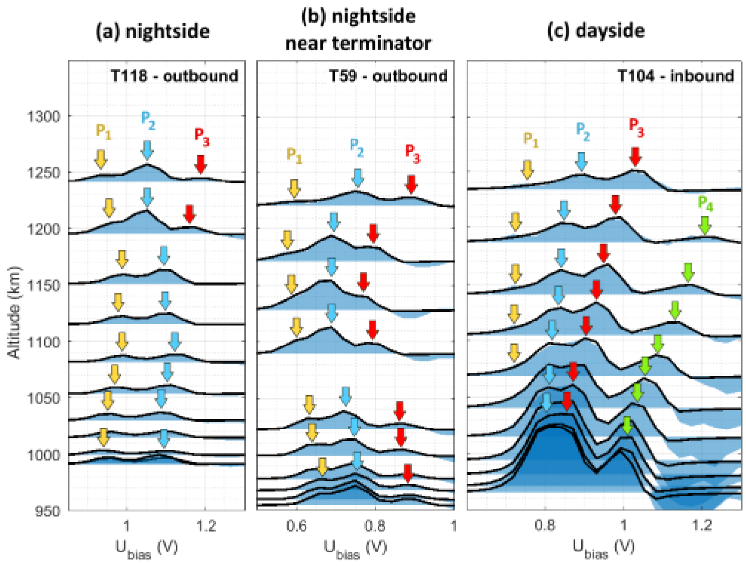

Fig 2. Detection of cold electron populations with d²I/dU²,
at different solar illuminations and altitudes.

4- Densities and temperatures for all the electron populations

Figures 3 and 4 give statistics on electron densities and temperatures measured for all the populations for the 57 Cassini flybys reaching at least 1200 km. They show that electron temperatures do not vary much with altitude between 1200 and 950 km, except for P_4. P_3 and P_4 have increasing densities with pressure on dayside.

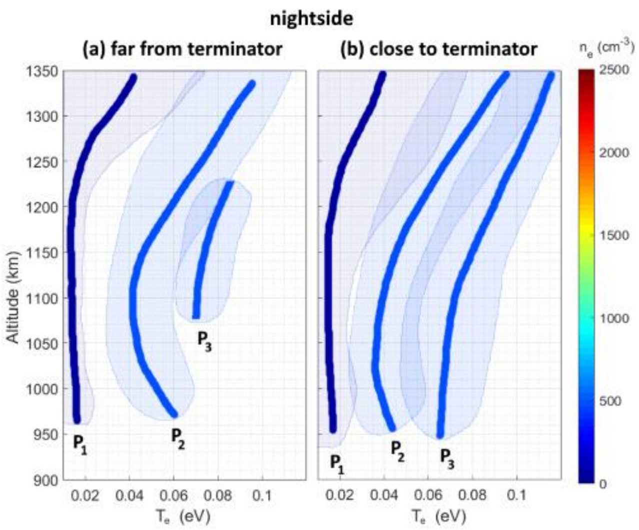

Fig 3. Electron densities and temperatures for the 4 populations.
Statistics on 30 nightside flybys.

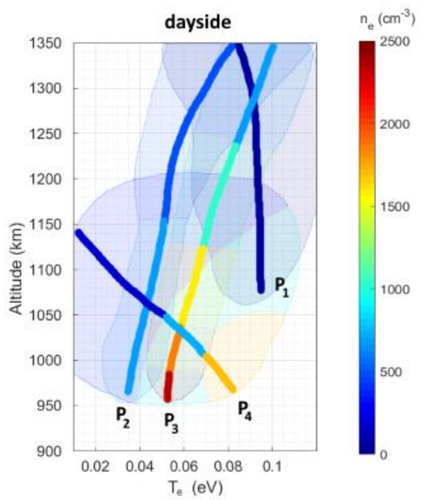

Fig 4. Electron densities and temperatures for the 4 populations.
Statistics on 34 dayside flybys.

5- Statistics

The large dataset enables to do statistics and search for correlations. In particular, we observe that P_3 and P_4 densities are correlated with the extreme UV flux. This enforces the idea that these populations are formed by processes involving solar photons (certainly UV).

We also observe a strong correlation between the density and the temperature of the P_4 population, as illustrated in Figure 5.

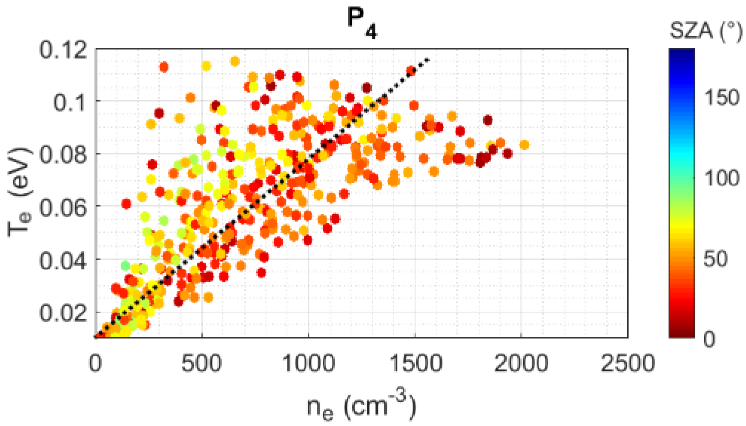

Fig 5. Linear correlation between density and temperature in the case of population P_4.
P_4 electrons are observed only on dayside, at a Solar Zenith Angle (SZA) < 90°.

6- Conclusion: origins of the detected electron populations

From the above results we suggest possible origins for the three populations P_2, P_3 and P_4, coming from the plasma surrounding the probe:

-P_2 is detected in all cases, at rather low density (~500 cm^{-3}) and temperature (~0.04 eV). These are supposed to be background thermalized electrons, possibly formed through collisions of gas species with magnetospheric suprathermal electrons.

-P_3 electrons are denser with stronger solar illumination and higher pressure (up to 3000 cm^{-3}). They are hotter than P_2 electrons (~0.06-0.07 eV). Therefore, they could be formed by the photo-chemistry occurring in Titan's ionosphere.

-P_4 electrons are only observed on dayside and below 1200 km, in the place where heavy negative ions and aerosols are present. We suggest two possible formation processes: (1) the photo-emission of electrons from grains could be triggered by photons of a few eV due to the negative charge born by the aerosols [5], [15]; (2) electrons could also be thermo-emitted from the grains, as a result of their heating by diverse processes such as heterogeneous chemistry, sticking of electrons or recombination of radicals [16].

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