# Negative ion densities in the deep ionosphere of Titan

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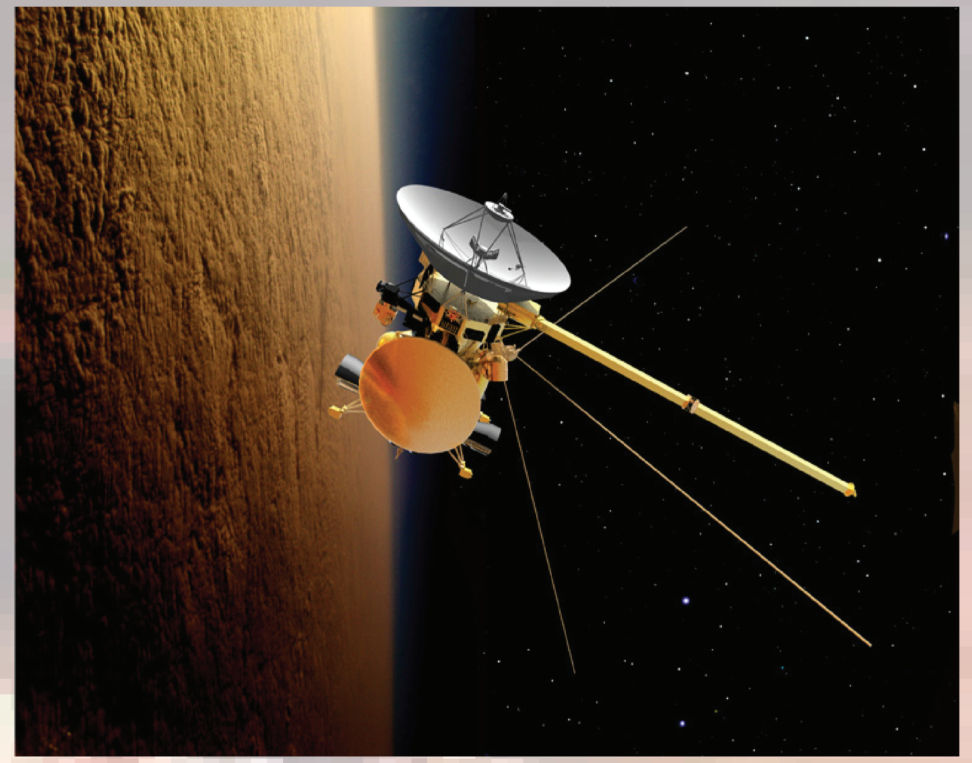
## Abstract

The Cassini s/c Radio and Plasma Wave Science (RPWS) Langmuir Probe (LP) *in-situ* measurements of Titan's ionosphere from 47 deep flybys map the charge densities of negative ions and number densities of positive ions and electrons wrt. solar zenith angle (SZA) and an altitude range of 880-1400 km. The electron number densities are consistent with earlier observations. Negative ion charge densities exhibit a trend that exponentially increases towards lower altitudes within the covered altitude range, especially evident on the nightside of Titan (SZA > 110°). The negative ion charge densities at the lowest traversed altitudes (near 960 km) are in the range 300-2500 cm$^{-3}$. Very few free electrons ($n_e/n_i \sim 0.1$-$0.7$) exist in the deepest regions (880-1050 km) of Titan's nightside ionosphere, instead negative and positive heavy (>100 amu) organic ions are dominant. We therefore believe a dusty/aerosol plasma exist here, similar to what is found in noctilucent clouds in Earth's mesosphere.

## Cassini Langmuir Probe current measurements

Saturn's largest moon Titan has a dense atmosphere with complex organic chemistry [1] which may be similar to early Earth's. Titan's upper atmosphere is ionized by various energy sources (solar EUV/X-rays, cosmic rays and energetic particles) [2-4], which supply the ion chemistry leading to aerosol (tholin) formation [1, 5]. Building blocks of aerosols - positive ions of up to 350 amu/q and negative ions of up to 10000 amu/q - were discovered by the Cassini s/c [1, 6]. These heavy species are dominant in the lower (<1000 km) layers of the ionosphere [7, 8]. We use 47 deep flybys of Titan's ionosphere to map the charge densities of positive and heavy negative ions wrt. altitude and solar zenith angle (SZA).



Artist's impression of Cassini near Titan.
Image credit: Frank Hettick, NSS Space Art Gallery

## Instrument clockworks

Principle of a Langmuir probe is very simple: by applying a voltage ($U_{bias}$) to the probe, plasma particles of opposite charge are attracted, generating a current from which plasma parameters can be derived (electron/ion temperatures, densities, speeds). Each measurement is done by sweeping $U_{bias}$ between ±32 or ±4 V in 512 steps during 0.5 s, yielding current as a function of voltage. Current to the probe is described by Orbital Motion Limited [9] approximation [10].

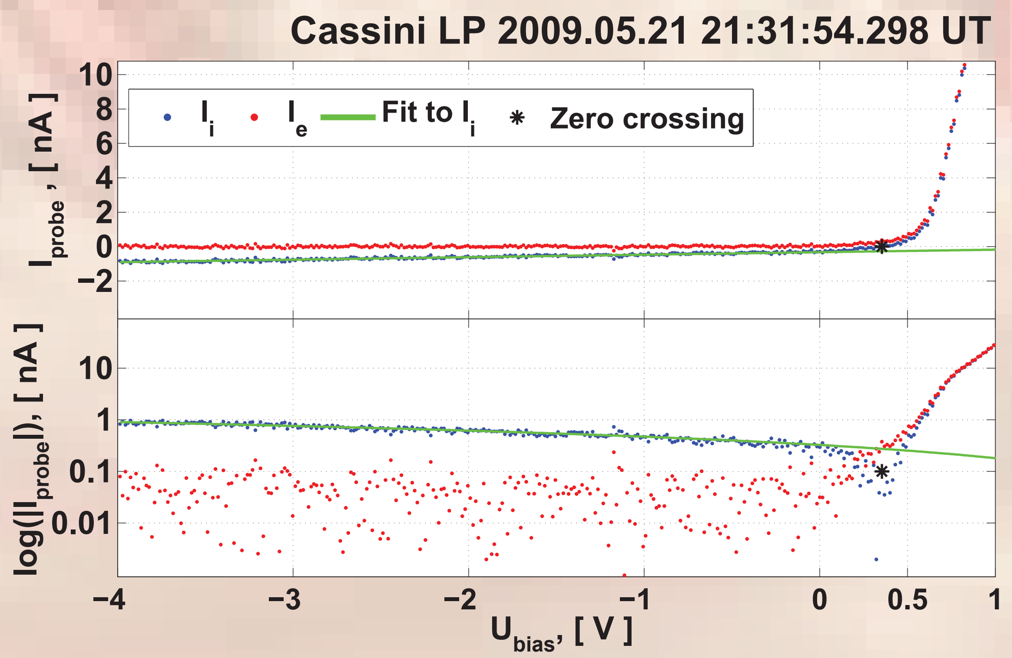



**Fig. 1** Example of an ion part of a Langmuir Probe sweep (blue), fit to data (green) and electron current (red). Star marks potential of zero current. For negative voltages, photoelectrons set the noise level to 100 pA.

## Experiment and analysis method

Since this study focuses on the ions, only $U_{bias} < 0$ side of the sweep is relevant. Figure 1 shows an example of such. Assuming single-charged positive ions [11] with average mass at least an order of magnitude less than average negative ion mass [7, 12, 13] and zero ion drift (ion speed ≈ s/c speed, $v_{sc}$), we use theoretical fit parameters to obtain positive and negative ion charge densities (also electron densities due to quasineutrality):

$$Z_n N_n \approx \frac{4}{q_e A_{LP}}\left(\frac{a}{v_{sc}} - \frac{b v_{sc} m_i}{2q_e}\right) \tag{1}$$

where $a$ and $b$ are the theoretical fit parameters, $Z_n N_n$ is the negative ion charge density, $A_{LP}$ is the LP surface area, $q_e$ is the electron charge, $v_{sc}$ is the spacecraft speed and $m_i$ is the positive ion mass. First term on the right-hand side corresponds to electron density and second term to positive ion density due to quasineutrality.

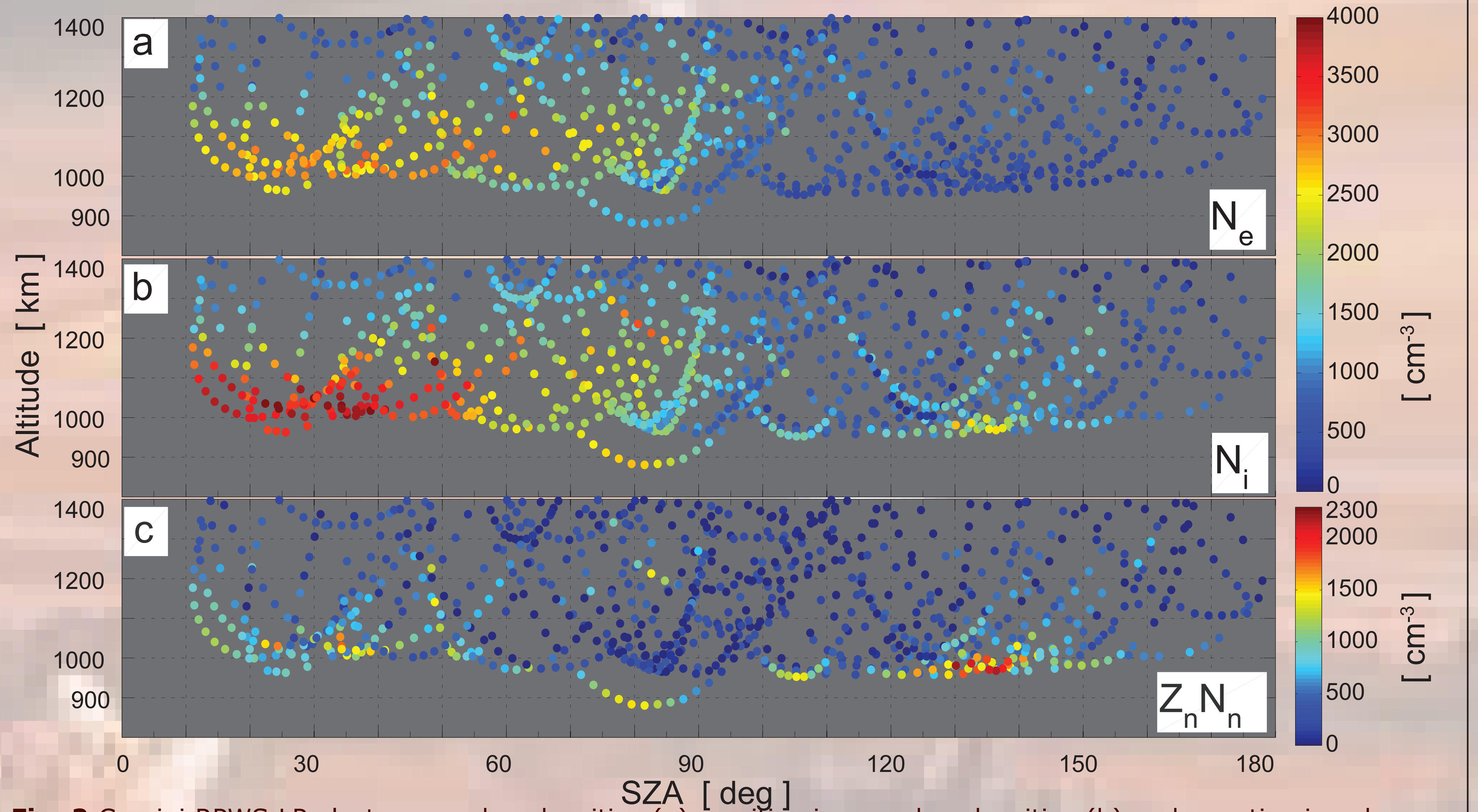



**Fig. 2** Cassini RPWS LP electron number densities (a), positive ion number densities (b) and negative ion charge densities (c) as functions of altitude and SZA. Each point is one measurement. Substantial charge densities of negative ions are observed below 1100 km for all covered SZAs. On the nightside of Titan (SZA > 110°) at these altitudes the electron population diminishes significantly and the plasma is largely dominated by ions, exhibiting properties of dusty plasma.

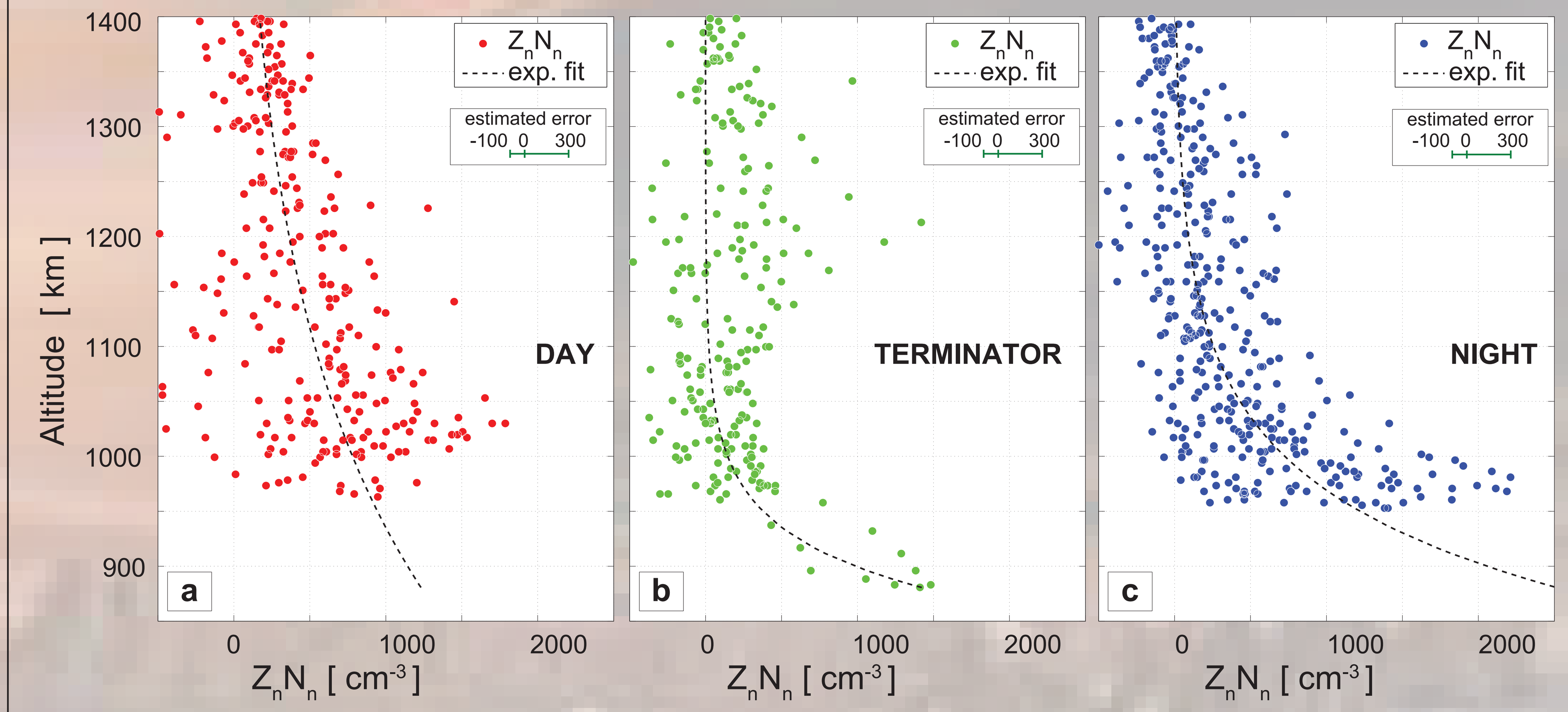



**Fig. 3** Altitude profiles of negative ion charge densities separated into three SZA intervals: Dayside (SZA<80°), Terminator (80°<SZA<110°) and Nightside (SZA>110°). Dashed lines are least-square exponential fits to the data. The error bar shows total estimated uncertainty, between -100 and +300 cm$^{-3}$. At dayside, large charge densities of negative ions ($Z_n N_n$) are detected at altitudes 1200-1400 km and the data points are spread out due to temporal ionosphere variations between the flybys. Terminator region shows an apparent decrease in $Z_n N_n$ due to solar radiation at Titan's ecliptic poles not penetrating to lower altitudes. Nightside data shows most clear exponential trend with $Z_n N_n$ also reaching highest values (up to 2500 cm$^{-3}$).

## Results

Based on 47 flybys of Titan's ionosphere in altitude range 880-1400 km we mapped the charge distribution of positive and heavy negative ions. Charge densities of negative ions (ZnNn) increase exponentially towards lower altitudes down to 880 km, reaching up to 2500 cm$^{-3}$. Positive ion densities reach up to 4200 cm$^{-3}$. Dayside ZnNn peak is seen just after 12 h LT, supporting dayside production by solar EUV. The importance of solar EUV for negative ion production is also indicated by an ecliptic polar minimum in ZnNn around 6 h LT. Titan's ionosphere below 1000 km exhibits properties of dusty plasma (negative charge carried by heavy ions rather than electrons). Estimation of dust grain charge gives at most 1-2 charges.

Presented data will be used to study production rates of pre-biotics, heavy organic molecules with masses 10$^2$-10$^4$ amu.

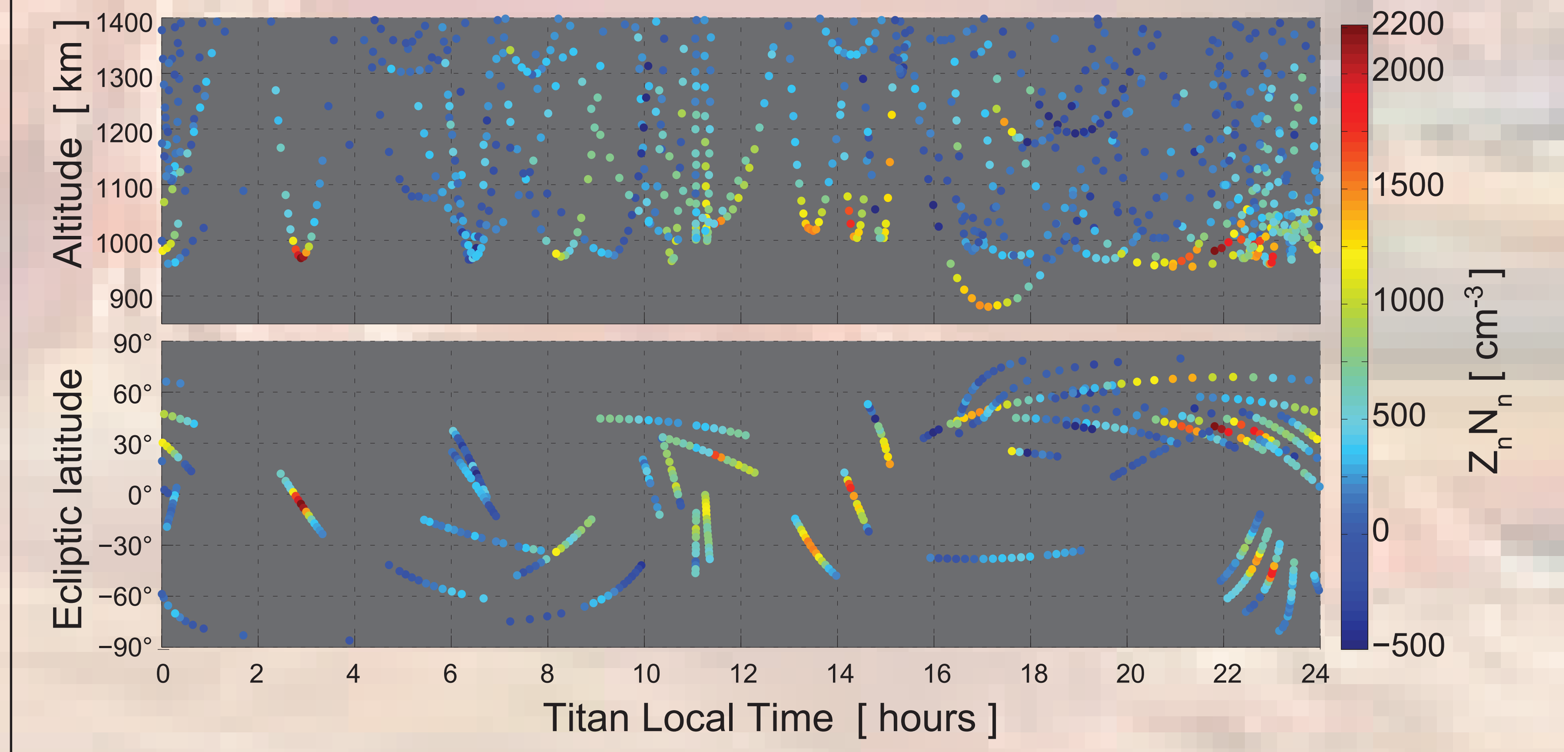



Fig. 4 (top) Titan Local Time (LT) dependence of the negative ion charge density $Z_n N_n$, showing dayside peak at ~14 h and "empty" regions at 6 and 18 h. (bottom) Cassini coverage of Titan in ecliptic coordinates, 90° is ecliptic north, -90° is ecliptic south. Data has been cut above 1200 km for clarity. Note: Time interval of 24 h LT corresponds to one Titan rotation period (16 days).

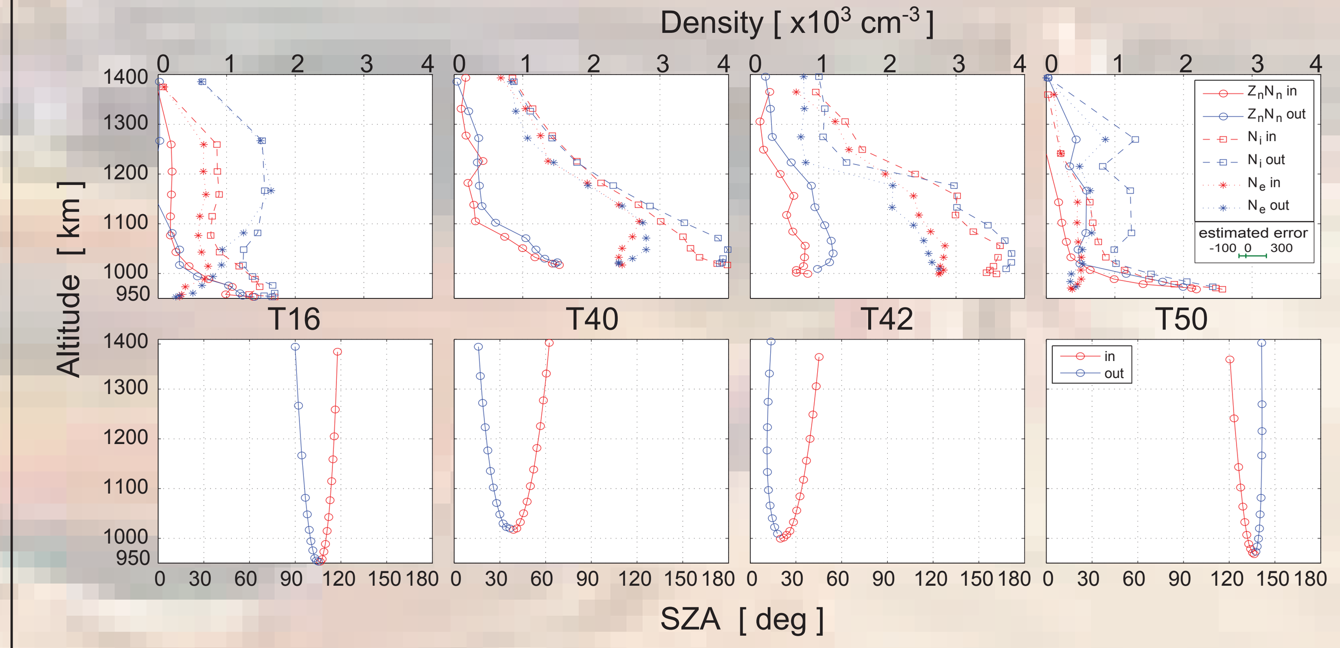



Fig. 5 Altitude profiles of electron number density (ne), positive ion number density ($n_i$) and negative ion charge density ($Z_n N_n$) for four individual flybys, T16, T40, T42 and T50, together with corresponding SZA profiles. Red colour shows the ingress data, blue colour shows the egress data. Error bar shows total estimated uncertainty, between -100 and +300 cm$^{-3}$.

## References

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