The far plasma wake of Titan from RPWS observations and hybrid simulations


RPWS team meeting, Iowa, March 2007
T9 Geometry

T9 flyby:
- CA 2005/12/26 18h59
  alt : 10 768km (wake)
- SLT : ≈ 3.h

- Strong asymmetry of the wake with respect to the « ideal » plasma wake
The extended « plasma tongue affects:
- the plasma density
- the direction of the flow
- the magnetic field direction
Are they UHR emissions?
\( f_p \approx 3 \text{kHz} \Rightarrow n_e \approx 0.1 \text{ cm}^{-3} \)

\( n_e \sim 0.6-0.8 \text{ cm}^{-3} \) (from ELS)
\( n_e \sim 1.6 \text{ cm}^{-3} \) (from LP)

\( f_{UHR} \approx f_p \propto \sqrt{n_e} \)
Density estimation from the LP

- LP well designed for dense and cold plasma
- In low density region, LP measurements are polluted with photoelectrons

\[ n_e \leq 1 \text{ cm}^{-3} \]

1- Usc derived from the sweeps analysis
2- \( n_e \) is deduced from the ELS-LP empirical relationship

\[ n_e \geq 1 \text{ cm}^{-3} \]

1- Assume that we have (at least) 2e-populations (photoelectrons + ambient electrons)
2- Photoelectrons can be indentified in the first derivative of the current.
T9 overview

- LP provides an estimation of the ion flux
  → Global increase of the flux assumed to be due to a change in the magnetospheric conditions

- The S/C was leaving the « periodic structure »
- Two separate increase of density in agreement with ELS observations

ELS observations (courtesy to Andrew Coates)
T9 LP overview

- Estimation of the speed from LP data:
  - From the DC level of the ion current
  - From the slope assuming the ion mass

- Region 1:
  - \( n_e \approx 10 \text{ cm}^{-3} \)
  - \( V \approx 10-20 \text{ km/s} \)
  - Heavy ion (mass 28 amu)
  - \( Ti \leq 15-60 \text{ eV} \)

- Confirmed by CAPS

- Region 2:
  - \( n_e \approx 1.6 \text{ cm}^{-3} \)
  - Velocity larger (\( > 80 \text{ km/s} \))
  - Light ion mass (mass 1-2 amu)
  - \( Ti \leq 100 \text{ eV} \)

- Estimation of the total outflow (assuming cylindrical geometry for the wake):
  - 2-7\( \times \)10^{25} ions/s

(Ta : \( \sim 10^{25} \text{ ions/s} \), Wahlund et al, 2005)
Physical component of the model

- Hybrid 3D multi-species model (*Matthews*, 1994)
  - Ions are characterized by a set of macroparticles
  - Electrons are treated as an inertialess fluid
  - Time evolution of the magnetic field

- Co-rotating plasma: collisionless plasma
  - O⁺, H⁺\textsubscript{thermal} and H⁺\textsubscript{energetic}

- Neutral exosphere: N₂, CH₄ and H₂

- Coupling neutral and charged species
  - Photo and electron impact ionisation
  - Charge exchanges:
    - Incident ions with neutral exospheric molecules
  - No dissociation, only single ionisation

Ionization rates are not imposed but are computed locally from neutral densities and ionization frequencies or cross sections
- «Planetary» plasma: N₂⁺, CH₄⁺ and H₂⁺
T9 simulation

- Upstream conditions:
  - Incoming plasma not aligned with ideal co-rotation direction deflection of:
    - 65° outward (error bar 50%) from CAPS
    - 40° outward from MAG (assuming a symmetrical tail and Cassini crosses the central axis)

- Simulation performed with a deflection of 12° reproduces the main signatures (obtained after different simulations performed for different directions)

- Background magnetic field mainly in the equatorial plane of Titan
T9 Plasma wake composition

- Heavy ions (16-28 amu) observed only in the Saturn side
- Light ions (1-2 amu) dominant on the anti-Saturn-side

- Plasma composition asymmetry probably due to the combination:
  - the magnetic field topology
  - The Saturn’s side is in sunlit

Courtesy to Frank Crary
Ionization sources and magnetic field topology

- Cassini crosses the two magnetic lobes

- Main ionization sources differ for light and heavy ions:
  - Heavy ions are produced by photoionization
  - $\text{H}_2^+$ ions are produced by charge exchange reactions

- Planetary ions are convected in the magnetic lobes
  - Similar to a polar outflow

- Estimation of the escaping plasma outflow:
  - In agreement with the observations ($2-7 \times 10^{25}$ ions/s)

<table>
<thead>
<tr>
<th></th>
<th>$\text{N}_2^+$</th>
<th>$\text{CH}_4^+$</th>
<th>$\text{H}_2^+$</th>
<th>all ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Escaping Flux ($\times 10^{25}$ ions.s$^{-1}$)</td>
<td>1.3</td>
<td>2.4</td>
<td>1.9</td>
<td><strong>5.6</strong></td>
</tr>
</tbody>
</table>
T9 Summary

- Strong asymmetry of the plasma wake
  - Not aligned with the expected plasma wake
  - Two separate signatures
    - Region 1: \( n_e \approx 10 \text{ cm}^{-3}, \ V \approx 10-20 \text{ km/s}, \ Ti < 15-60 \text{ eV} \)
    - Region 2: \( n_e \approx 1 \text{ cm}^{-3}, \ V > 80 \text{ km/s}, \ Ti < 100 \text{ eV} \)
- Change in the plasma composition
  - Heavy ions (16-28 amu) observed on the Saturn’s side (dayside)
  - Light ions (1-2 amu) identified on the anti-Saturn’s side
- 3D hybrid simulation succeed to reproduce main of the observations.
  - Density, plasma composition, magnetic field signatures
  - Asymmetry mainly due to a combination between:
    - Asymmetric production rate (day/night asymmetry)
    - Magnetic field morphology
- Difference with the observations:
  - Deficiencies in the simulation model (coarse simulation grid (500 km), ...)
  - Change in the magnetopsheric condition during the flyby
- Estimation of the escaping plasma outflow
  - \( 2-7 \times 10^{25} \text{ ions/s} \) from the LP analysis (assuming a cylindrical symmetry)
  - \( \approx 5 \times 10^{25} \text{ ions/s} \) from hybrid simulations
  - \( Ta \approx 10^{25} \text{ ions/s} \) (Wahlund et al, 2005), Voyager 1: \( 2 \times 10^{24} \text{ ions/s} \) (Gurnett et al, 1982)