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

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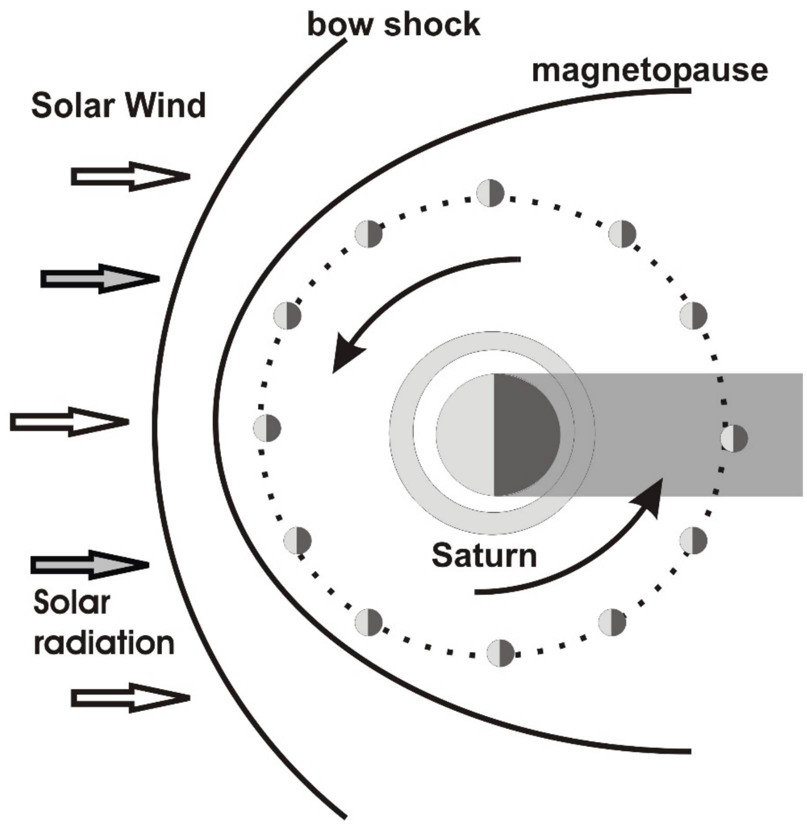
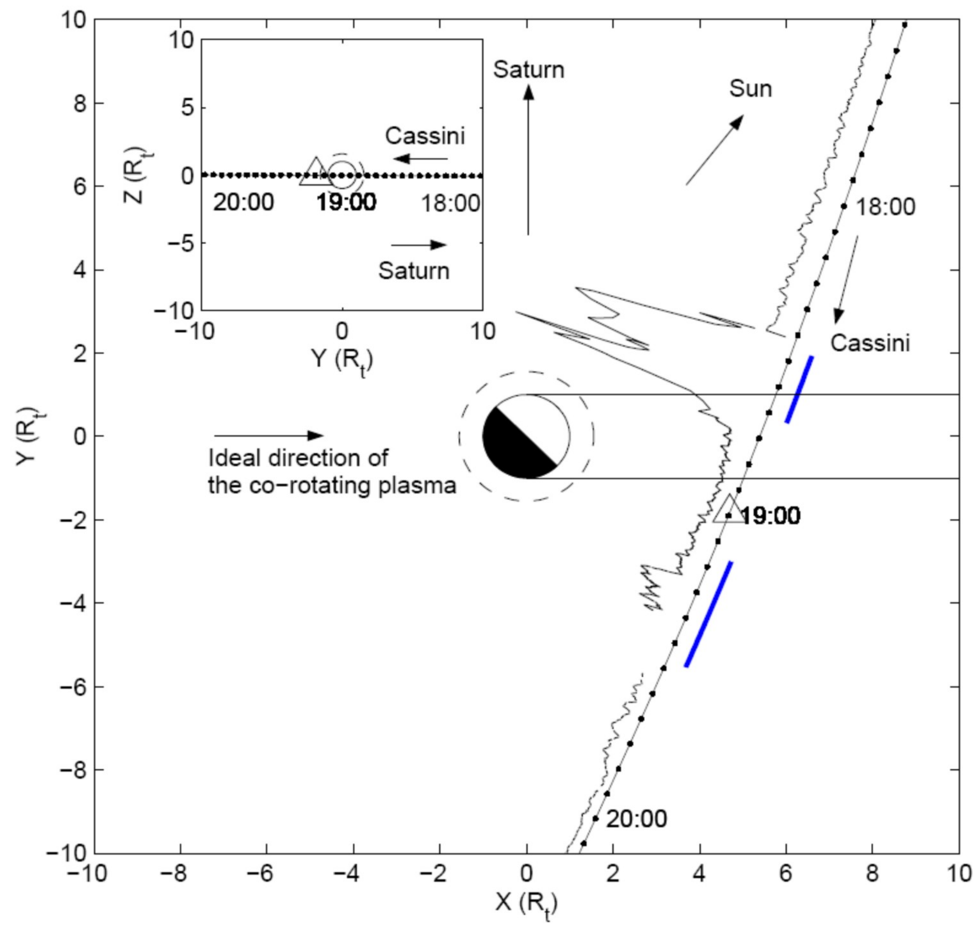
# T9 Geometry

T9 flyby:

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

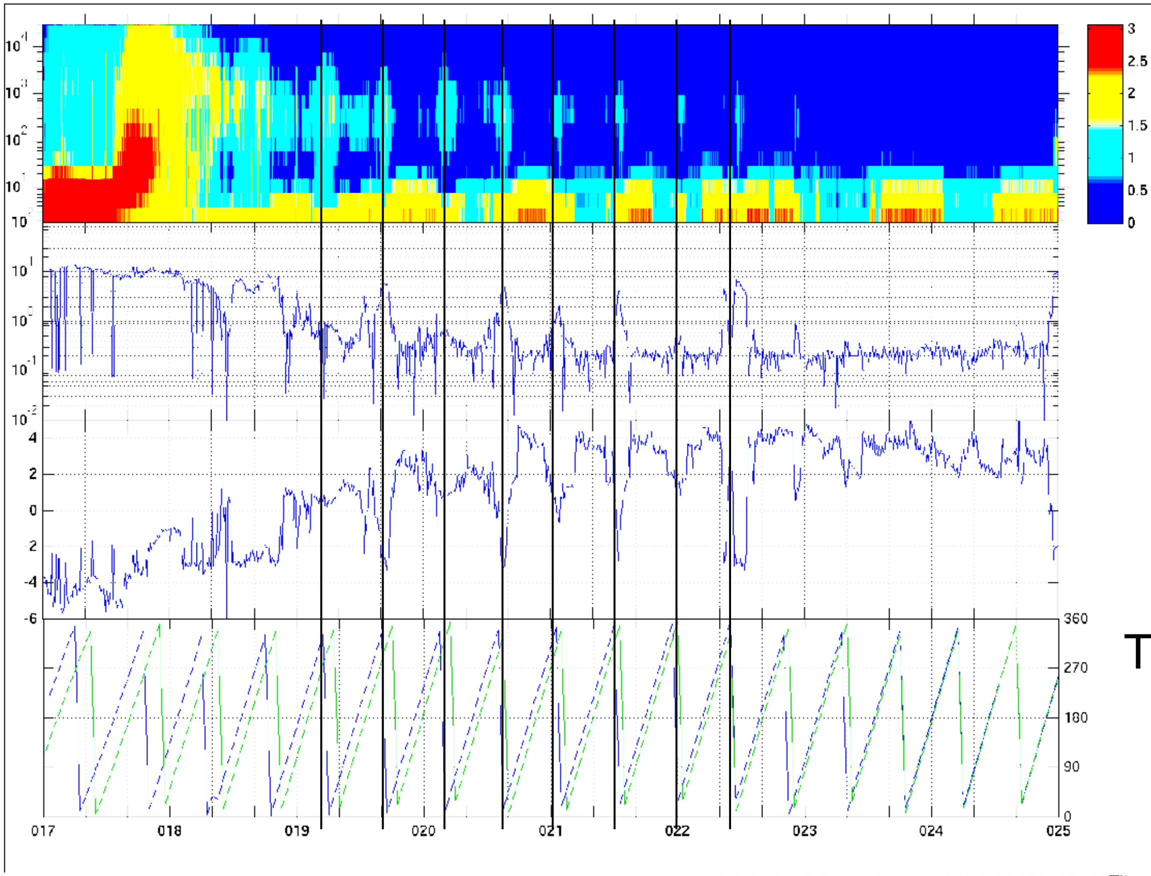


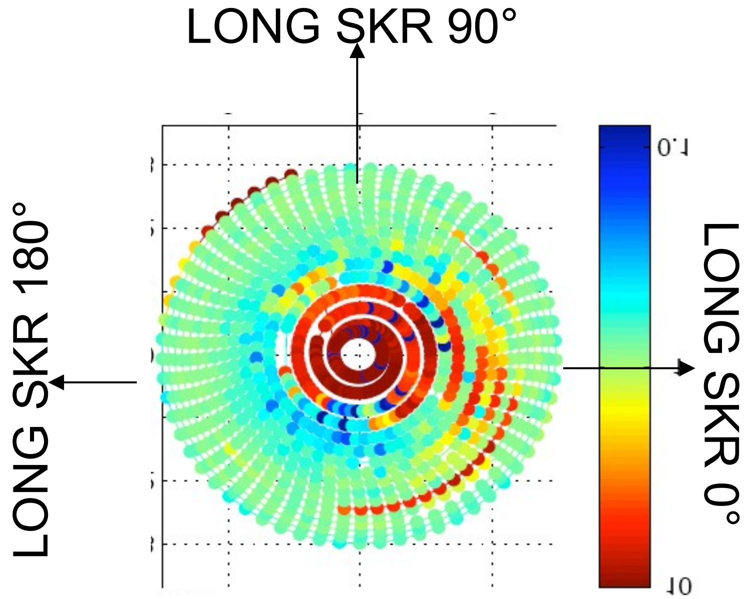




- Strong asymmetry of the wake with respect to the « ideal » plasma wake

# Upstream conditions

Rev 20 outbound



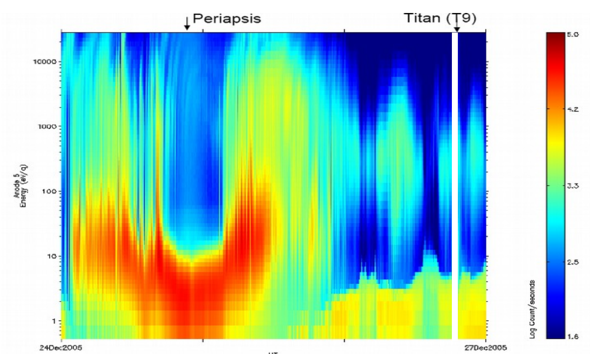




The extended « plasma tongue affects :

- the plasma density
- the direction of the flow
- the magnetic field direction

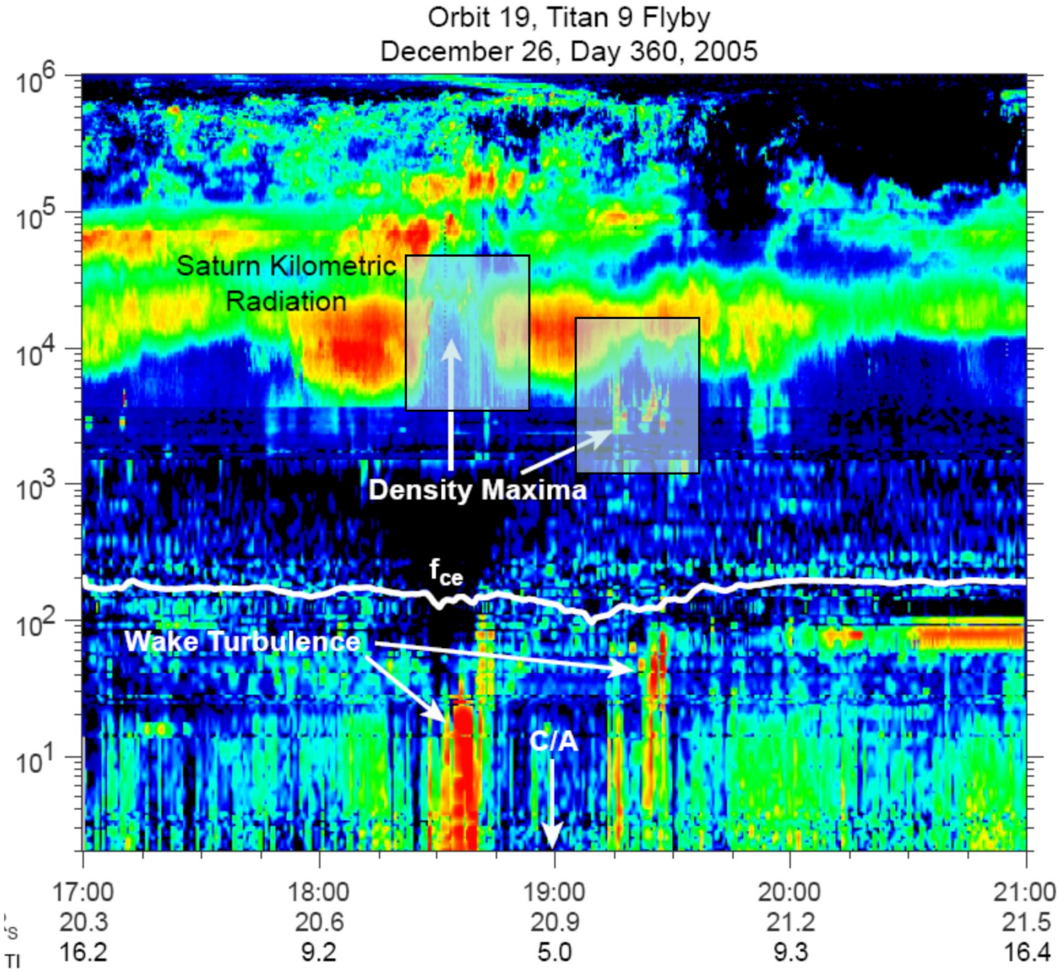
ELS observations Anode 5 (courtesy to Andrew Coates)

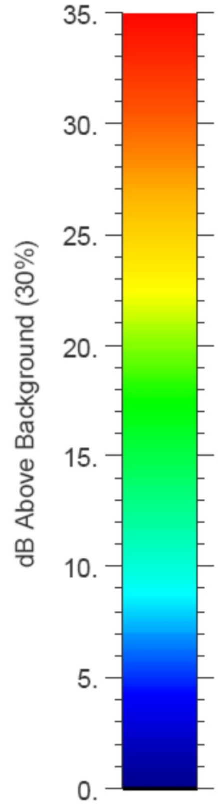
T9 inside this periodic structure

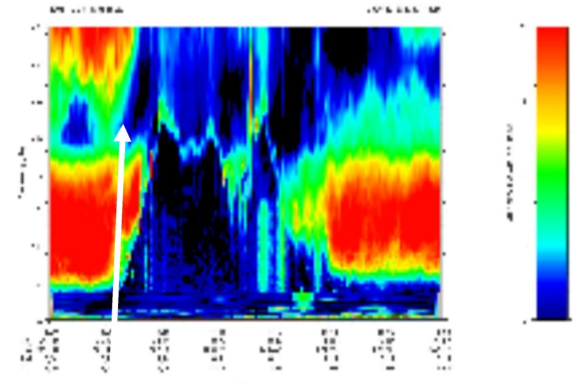



Rev19

# RPWS observations



UHR emissions observed

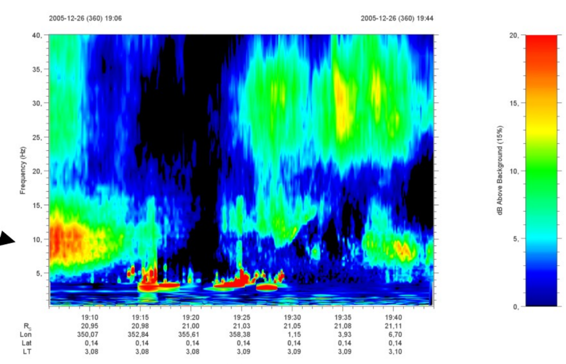
$$f_{UHR} \cong f_p \propto \sqrt{n_e}$$

Are they UHR emissions ?

$f_p \approx 3kHz \Rightarrow n_e \approx 0.1\ cm^{-3}$

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

$n_e \sim 1.6\ cm^{-3}$ (from LP)



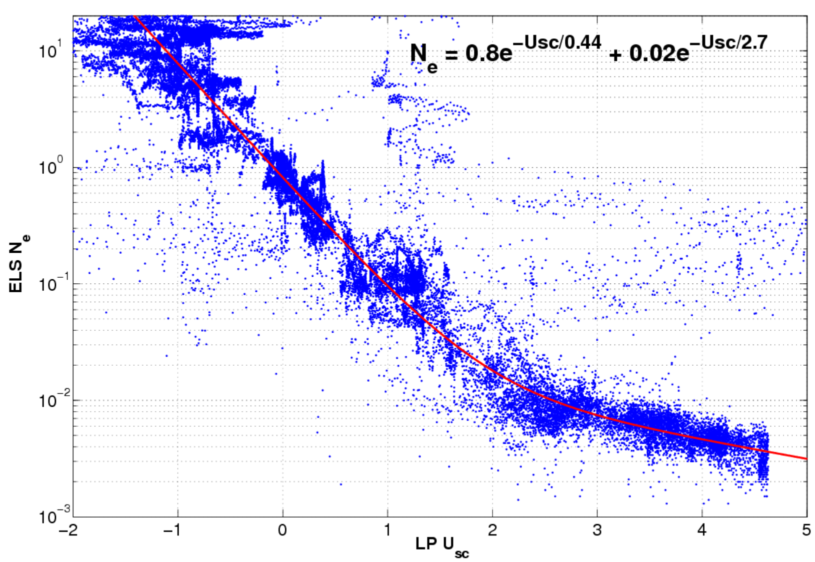
# Density estimation from the LP

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

$$n_e \leq 1\, cm^{-3}$$

1- Usc derived from the sweeps analysis

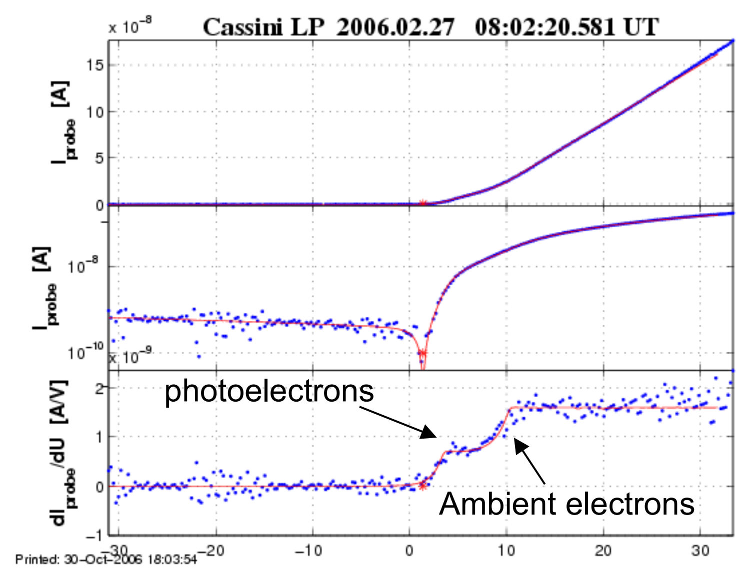
2- $n_e$ is deduced from the ELS-LP empirical relationship



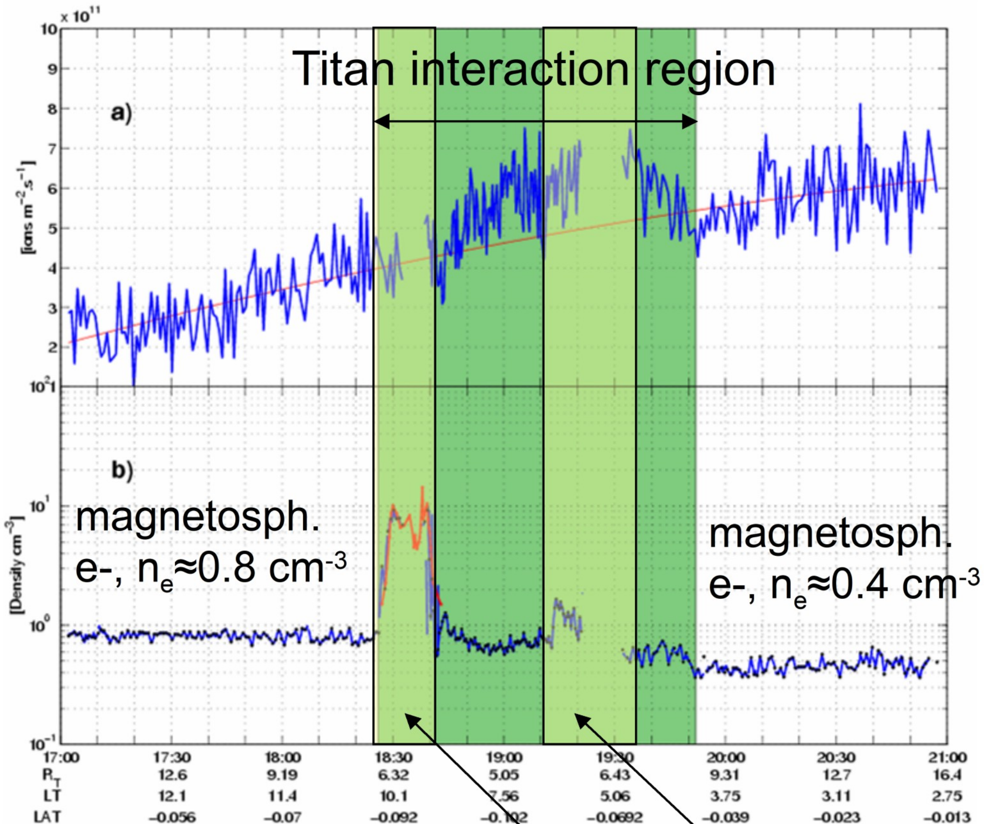

$$n_e \geq 1\, cm^{-3}$$

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

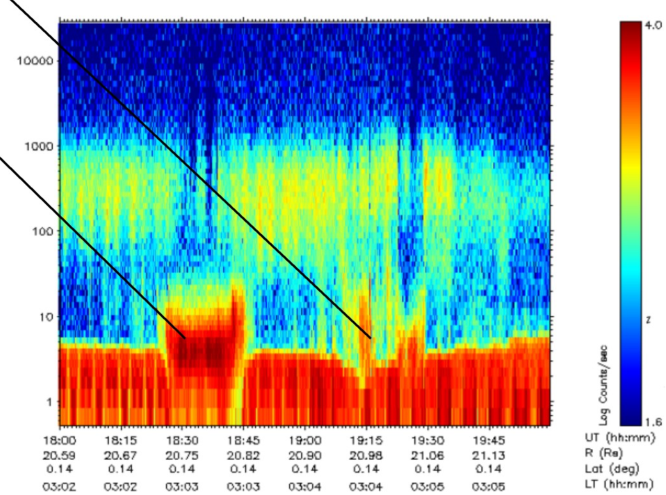



- ☐ LP provides an estimation of the ion flux

→Global increase of the flux assumed to be due to a change in the magnetospheric conditions

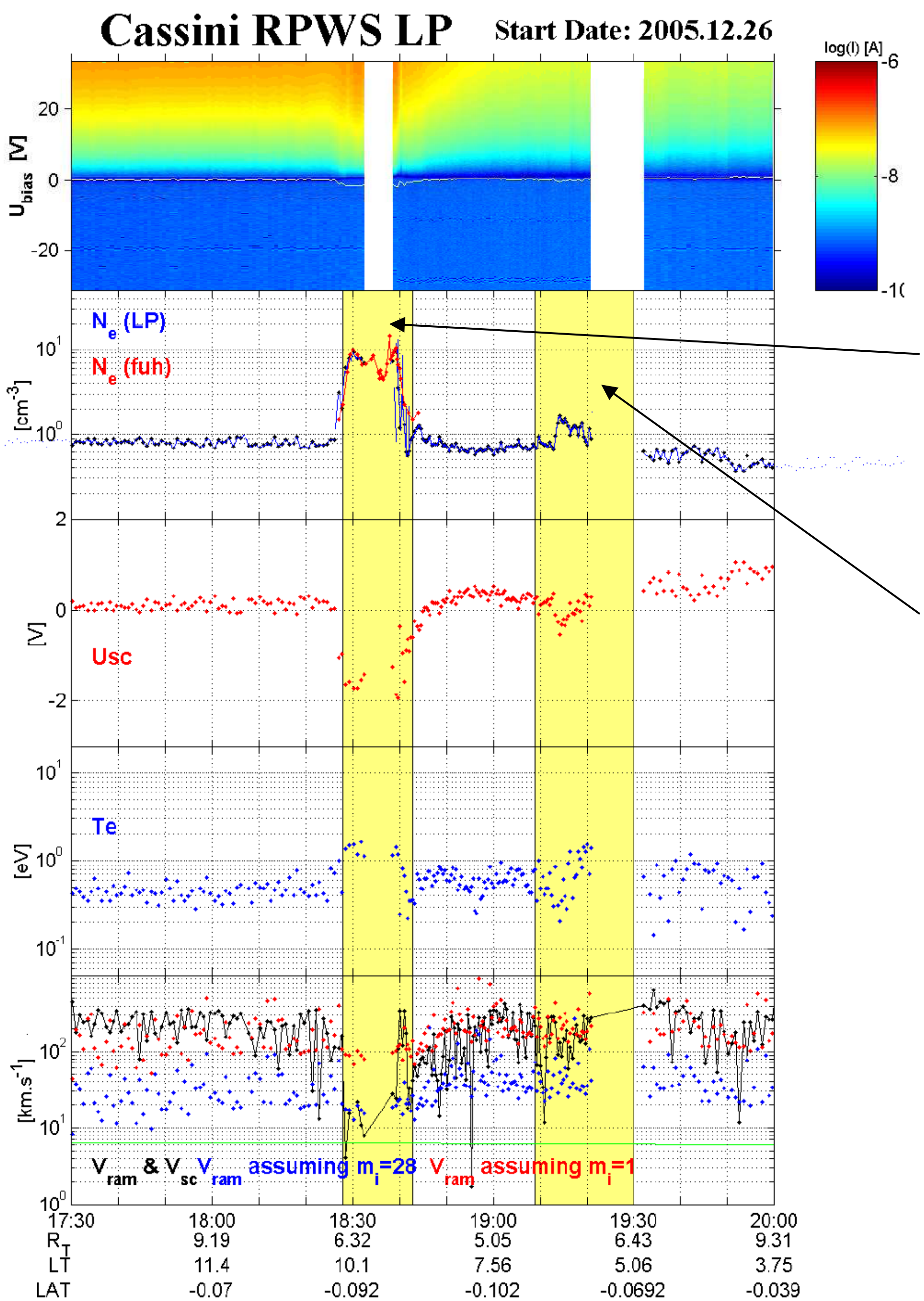
The S/C was leaving the « periodic structure »

- ☐ 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 :
  - $n_e \approx 10$ cm$^{-3}$
  - V≈10-20 km/s
  - Heavy ion (mass 28 amu)
  - Ti≤ 15-60 eV
- Region 2 :
  - $n_e \approx 1.6$ cm$^{-3}$
  - Velocity larger (> 80 km/s)
  - Light ion mass (mass 1-2 amu)
  - Ti ≤ 100eV

✓ Confirmed by CAPS

- Estimation of the total outflow (assuming cylindrical geometry for the wake) : 2-7x$10^{25}$ ions/s (Ta : ~$10^{25}$ ions/s, Wahlund et al, 2005)

# Physical component of the model

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

- ☐ Co-rotating plasma : collisionless plasma
  - ➢ $O^+$, $H^+_{thermal}$ and $H^+_{energetic}$
- ☐ Neutral exosphere : $N_2$, $CH_4$ and $H_2$
- ☐ 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**

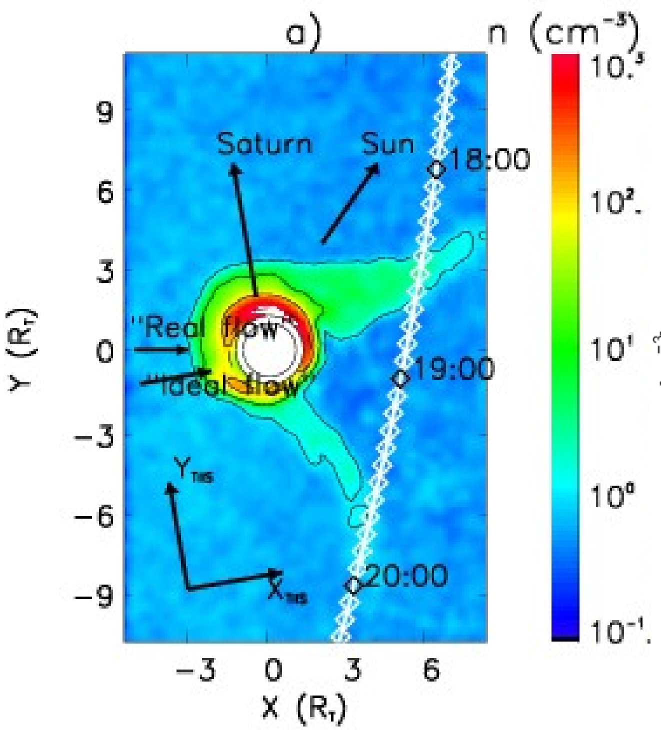
- ➢ « planetary » plasma : $N_2^+$, $CH_4^+$ and $H_2^+$

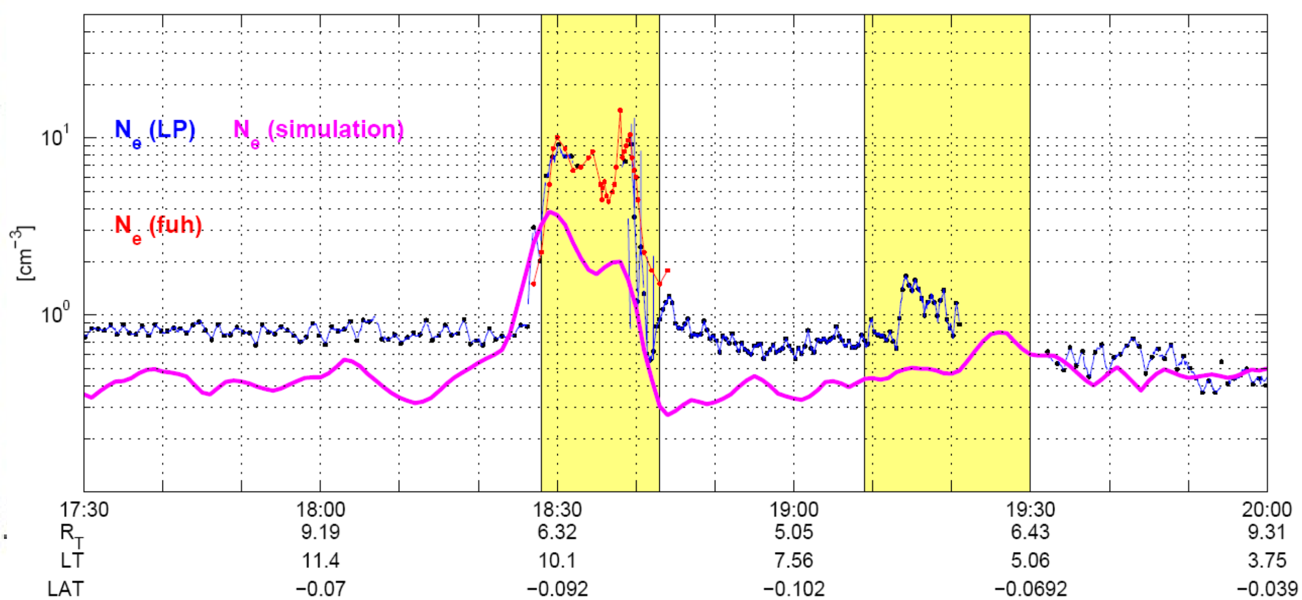
# T9 simulation

☐ 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)

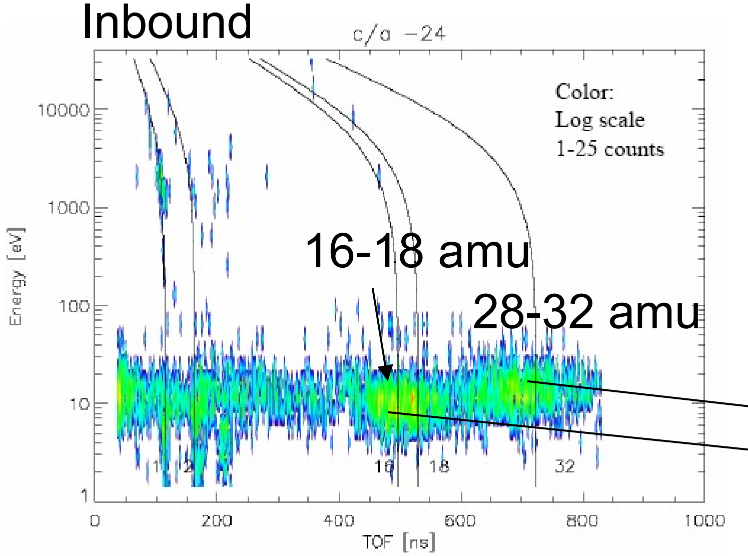
☐ Background magnetic field mainly in the equatorial plane of Titan



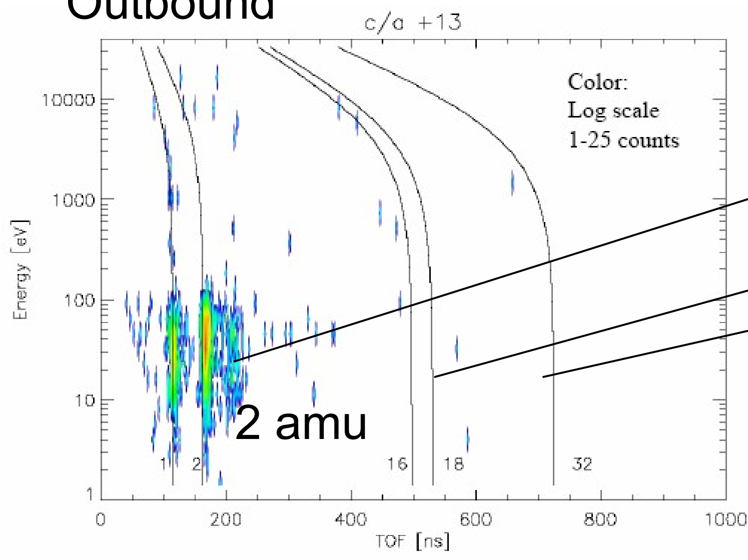



# T9 Plasma wake composition

Inbound

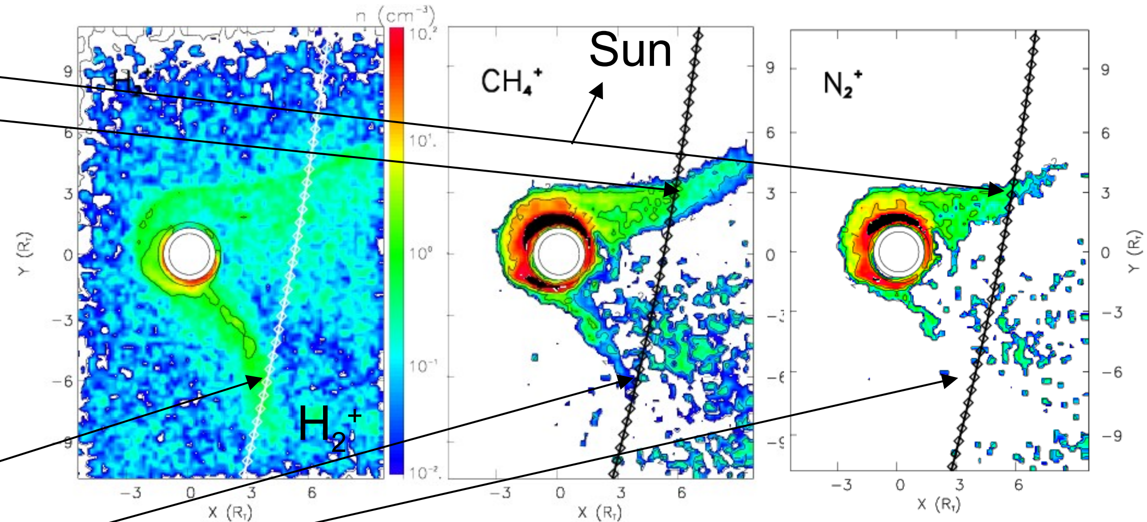



Outbound




Courtesy to Frank Crary

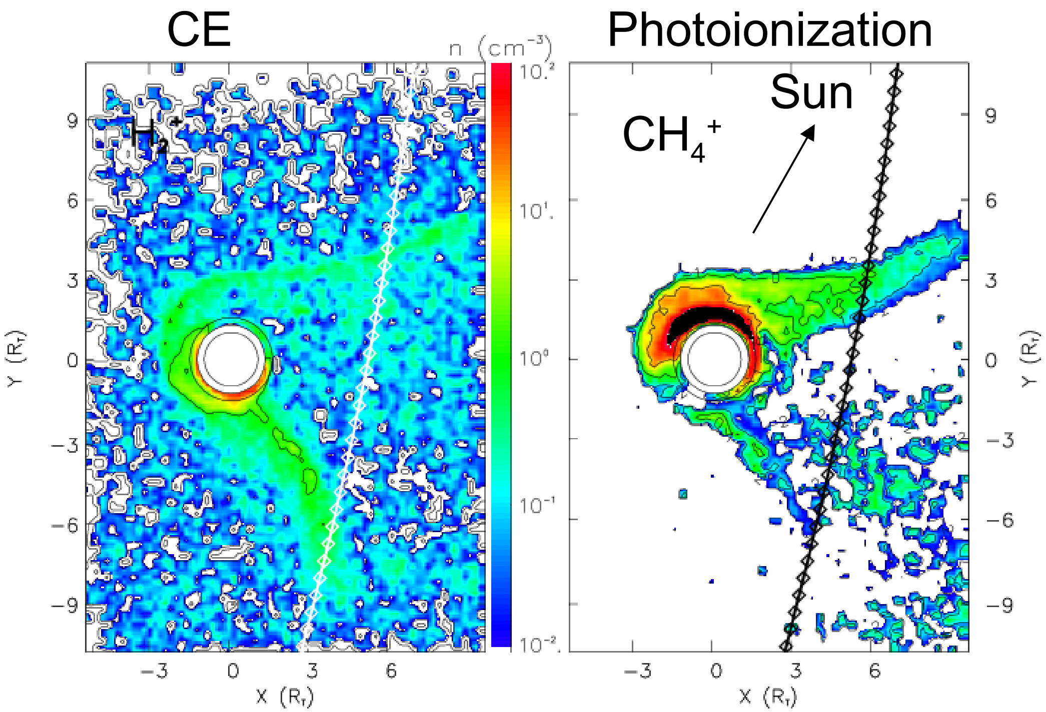
- Heavy ions (16-28 amu) observed only in the Saturn side
- Light ions (1-2 amu) dominant on the anti-Saturn-side



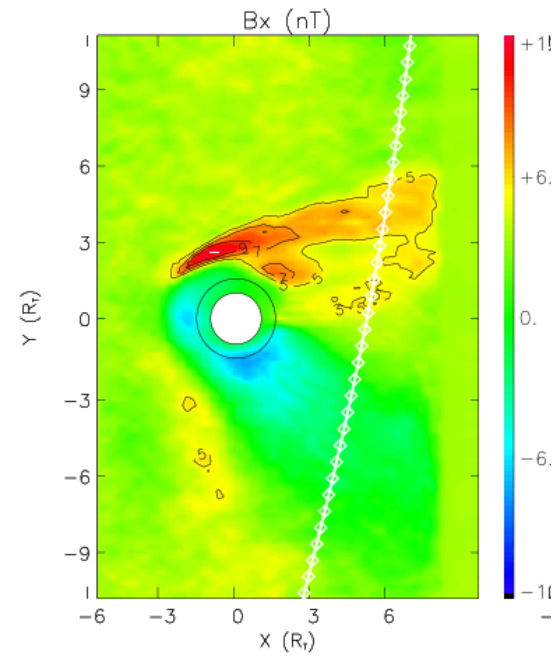

- Plasma composition asymmetry probably due to the combination:

- the magnetic field topology
- The Saturn's side is in sunlit

# Ionization sources and magnetic field topology




➢ Cassini crosses the two magnetic lobes




➢ Main ionization sources differs for light and heavy ions :

- Heavy ions are produced by photoionization
- H2+ 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 $10^{25}$ ions/s)

Escaping Flux ($\times$ $10^{25}$ ions.s$^{-1}$)

| $N_2^+$ | $CH_4^+$ | $H_2^+$ | all ions |
|---|---|---|---|
| 1.3 | 2.4 | 1.9 | 5.6 |

# T9 Summary

- Strong asymmetry of the plasma wake
  - Not aligned with the expected plasma wake
  - Two separate signatures
    - Region 1 : $n_e \approx 10$ cm$^{-3}$, V≈10-20 km/s, Ti<15-60 eV
    - Region 2 : $n_e \approx 1$ cm$^{-3}$, V>80 km/s, Ti < 100eV
  - 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 similation 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
  - $2\text{-}7 \times 10^{25}$ ions/s from the LP analysis (assuming a cinlidrical symetry)
  - $\approx 5 \times 10^{25}$ ions/s from hybrid simulations
  - Ta $\approx 10^{25}$ ions/s (Wahlund et al, 2005), Voyager 1 : $2 \times 10^{24}$ ions/s (Gurnett et al, 1982)