Titan in Saturn's Magnetosphere:

The Cassini Plasma Spectrometer (CAPS) Investigation

→ The experiments begin on October 26, 2004 ←

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Titan: From Discovery to Encounter

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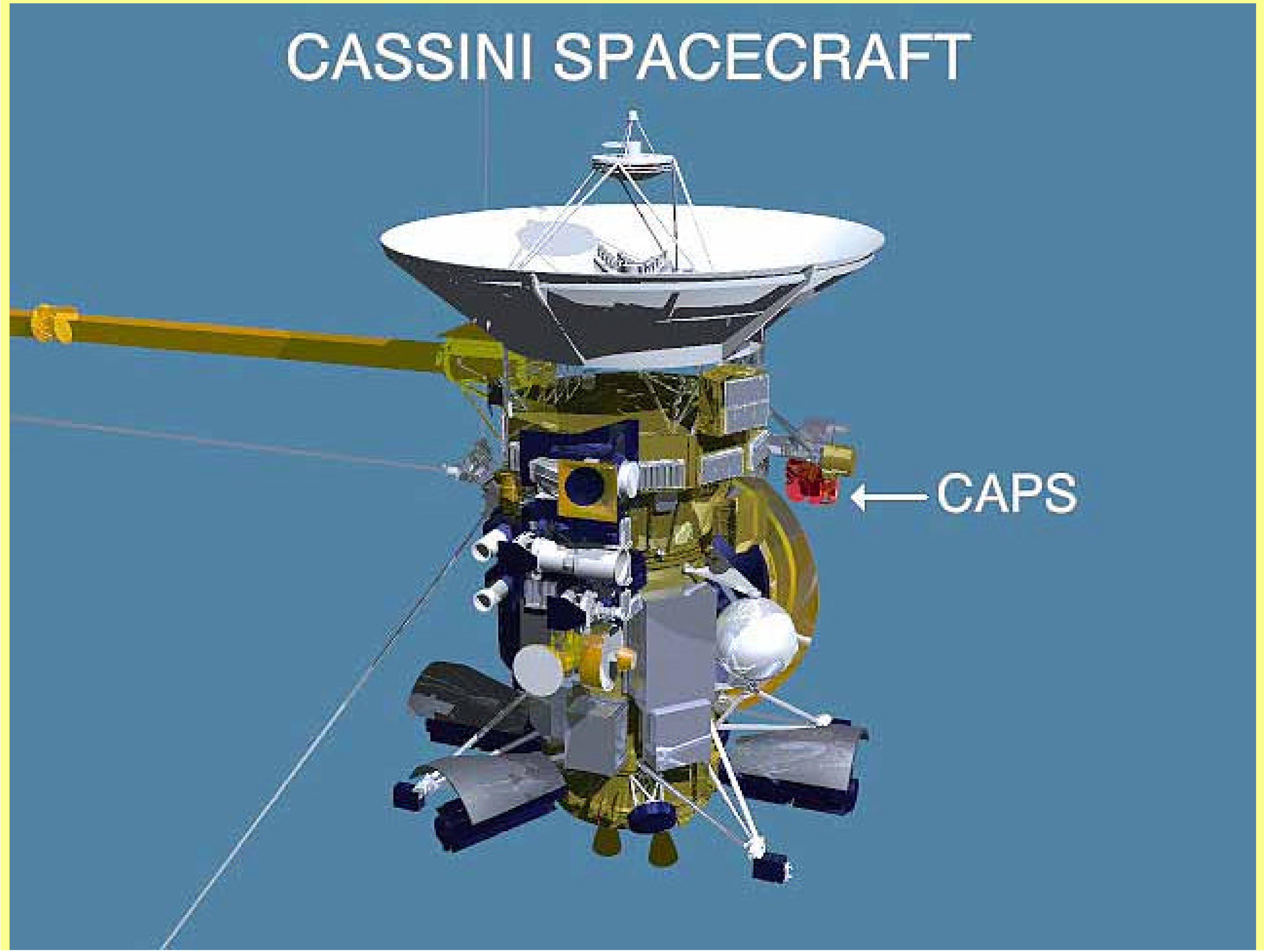
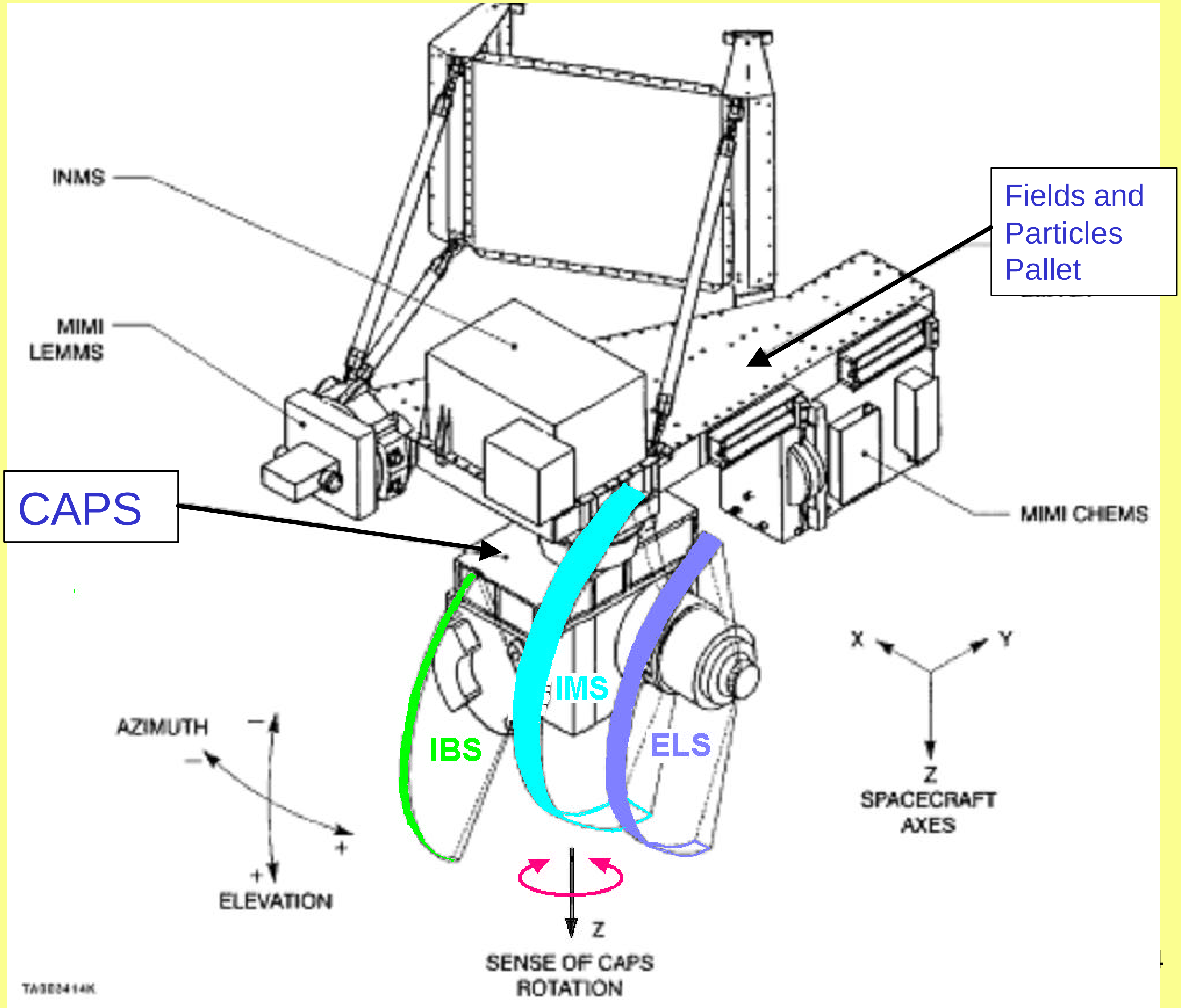
- Voyager data are the (very limited) canonical basis for our current understanding of Titan's ionosphere and magnetosphere and interactions with Saturn's magnetosphere.

- The goal of CAPS (and MAPS*) investigations is to update and vastly extend our knowledge of Titan (*our motto: 10 x Voyager!*).

*Magnetosphere and Plasma Science Working Group


CASSINI SPACECRAFT
CAPS


INMS
MIMI
LEMMS
CAPS
Fields and
Particles
Pallet
MIMI CHEMS
IMS
IBS
ELS
AZIMUTH
ELEVATION
X
Y
Z
SPACECRAFT
AXES
Z
SENSE OF CAPS
ROTATION

CAPS' fundamental goal is to measure and interpret the *distribution function* f_i *(**r**, **v**, t)* for all plasma components:

i => electrons and ions of all species

- **Electrons => ionization source**
- **Titan species => chemistry, bulk plasma processes, tracers**
- **Saturnian species => sputtering**

– **r** => location

- **Relative to Titan (upstream, ionosphere x-section, wake, flux tube)**
- **Relative to Saturn (local time)**

– **v** => 3-D velocity vector

- **Preferred directions: s/c ram, Saturn co-rotation, and magnetic field**

– t => time scales

- **Fast time resolution (2 ~ 4 s) for 2-D dynamics & major ion composition**
- **Moderate time resolution (3 ~ 4 min) for 3-D & high mass resolution**
- **Comprehensive survey for synoptic studies**

CAPS Measurement Capabilities

CAPS consists of 3 sensors:

Electron Spectrometer

Energy range: 0.6* to 28,750 eV

Field-of-view: 5.2° x 160°

Sensitivity (Titan): 3300 cts/s/el/cm^3

Resolution: 0.17 ΔE/E

Resolution: 5.2° x 20°

Ion Beam Spectrometer

Energy range: 1.0* to 49,800 eV

Field-of-view: 1.5° x 160°

Sensitivity (Titan): 3200 cts/s/ion/cm^3

Resolution: 0.014 ΔE/E

Resolution: 1.5° x 1.5°

Ion Mass Spectrometer

Energy range: 1.0* to 50,280 eV

Field-of-view: 8.3° x 160°

Mass range: 1 to 100 amu

Resolution: 0.17 ΔE/E

Resolution: 5.2° x 20°

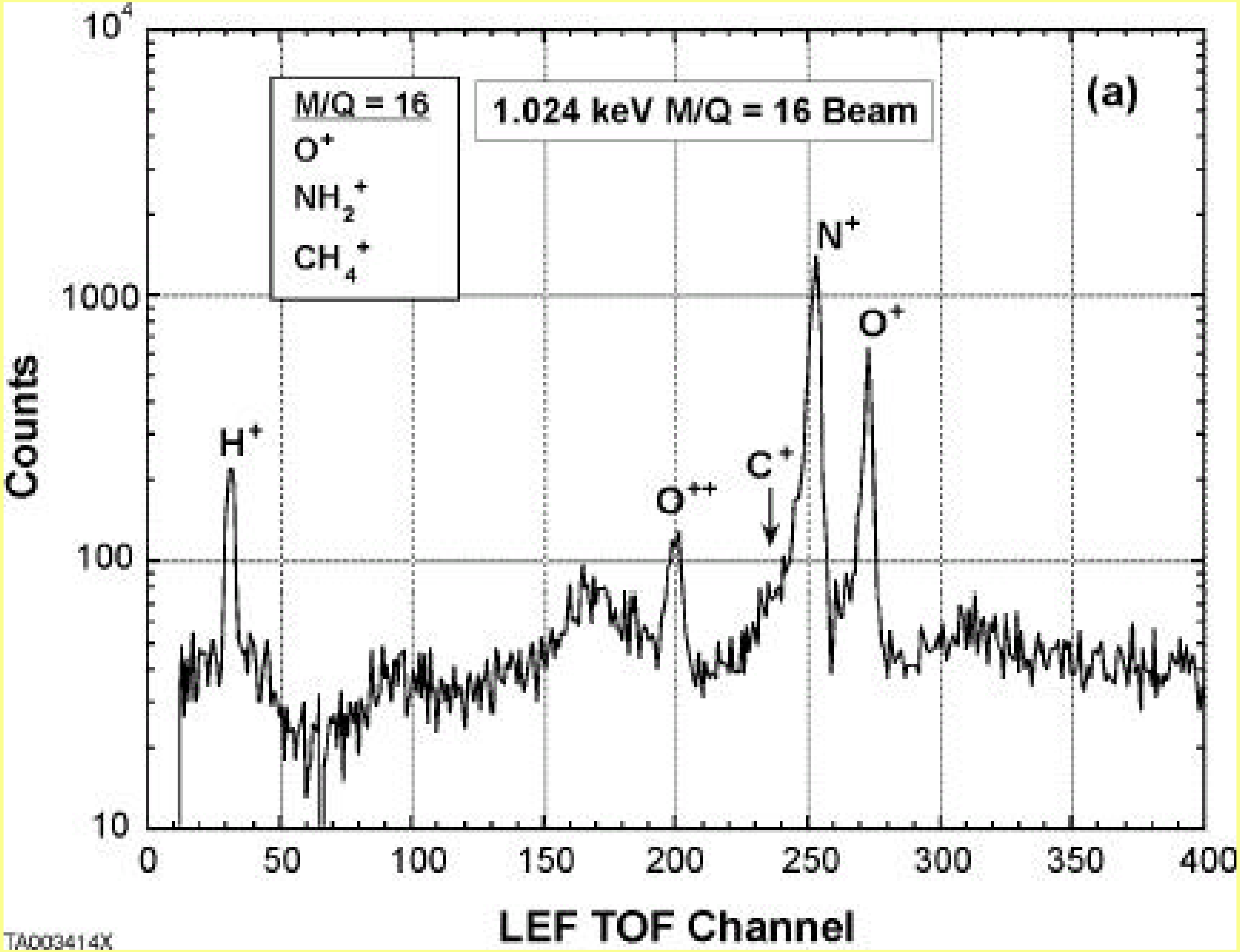
Resolution (atomic): 60 M/ΔM

Resolution (mol.): ~2600 M/ΔM

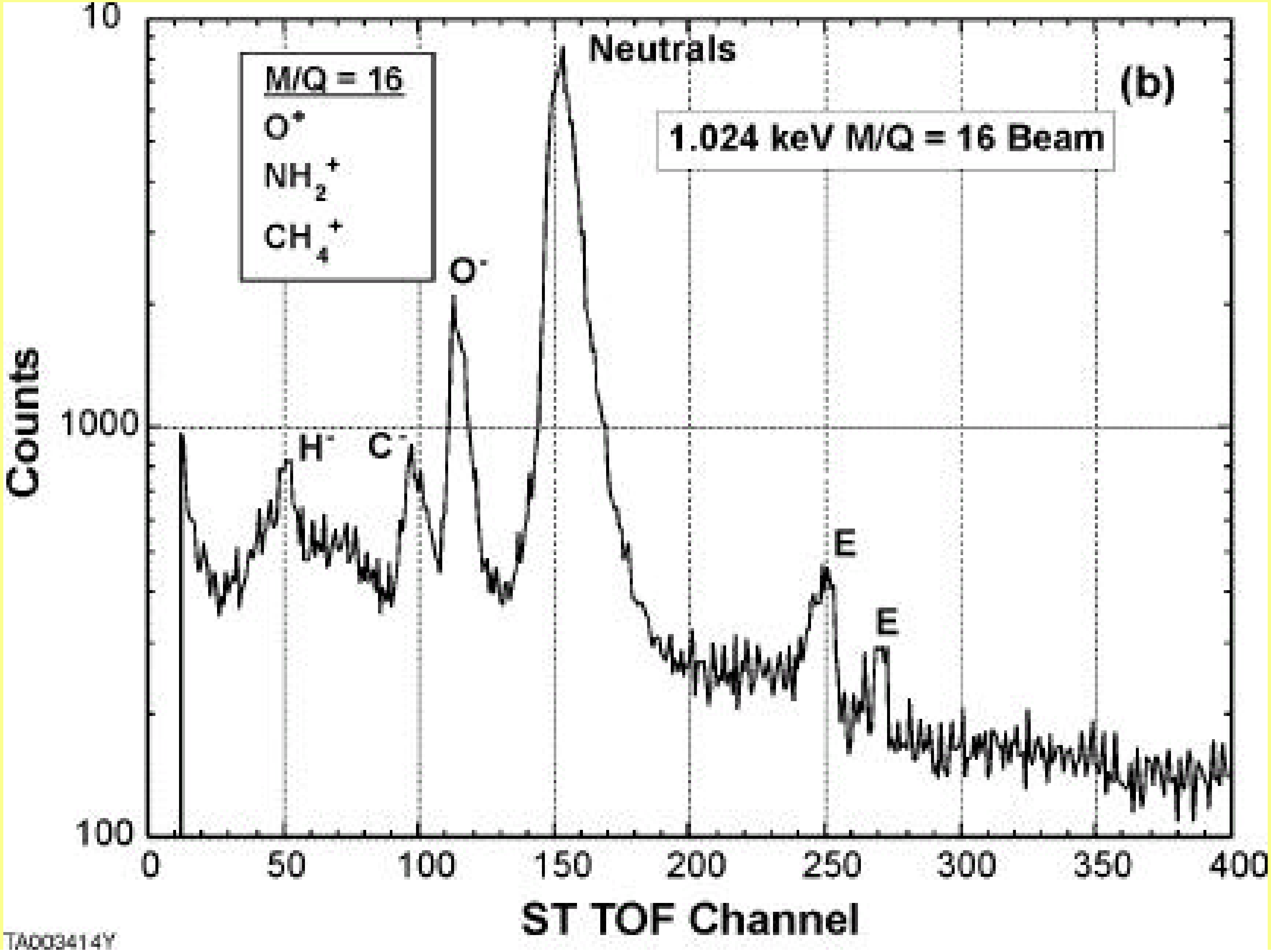
Sensitivity (Titan): 500 cts/s/ion/cm^3

* May be limited by spacecraft potential

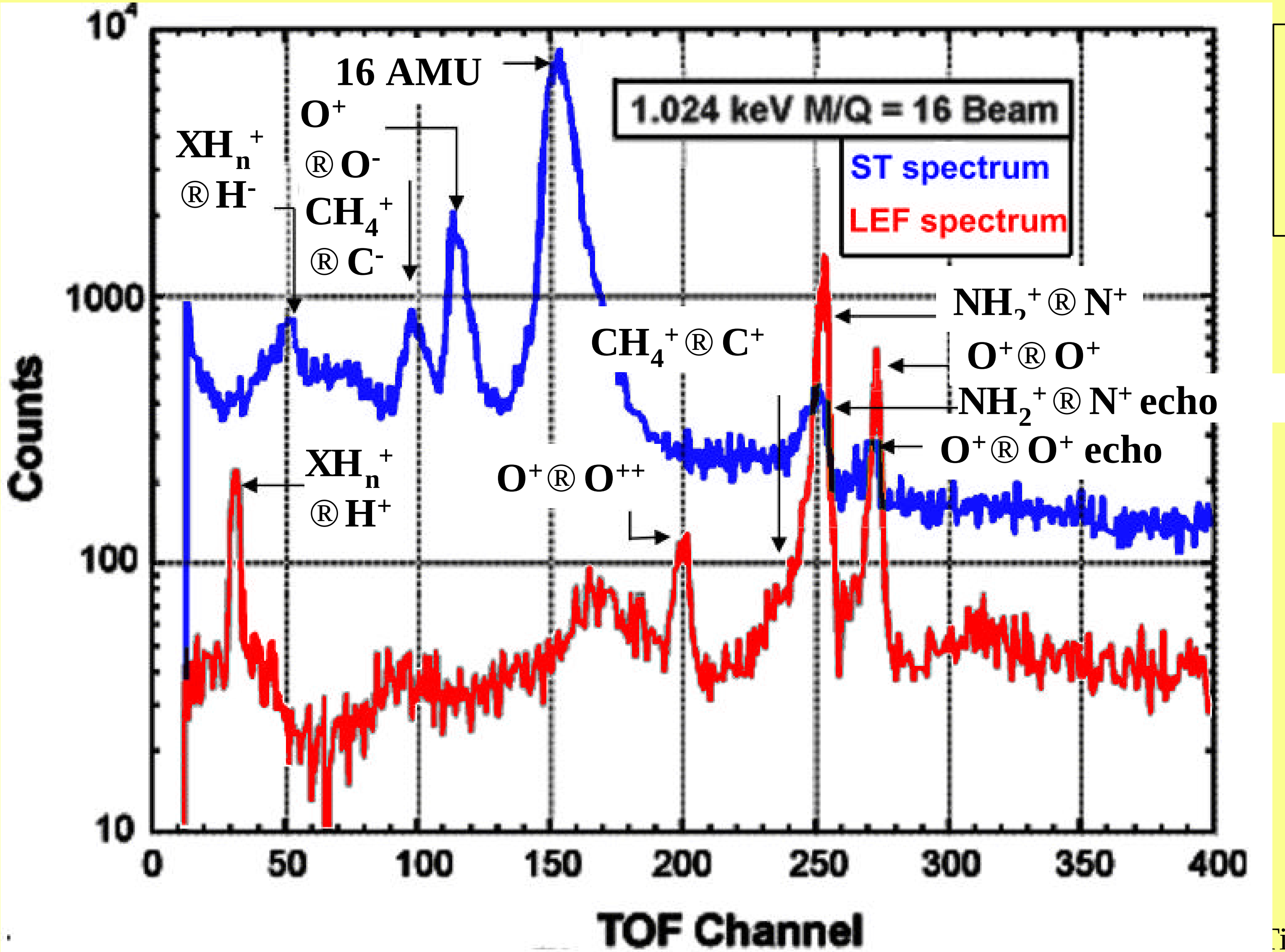
IMS capability for splitting isomers—high resolution spectrum



IMS capability for splitting isomers—low resolution spectrum

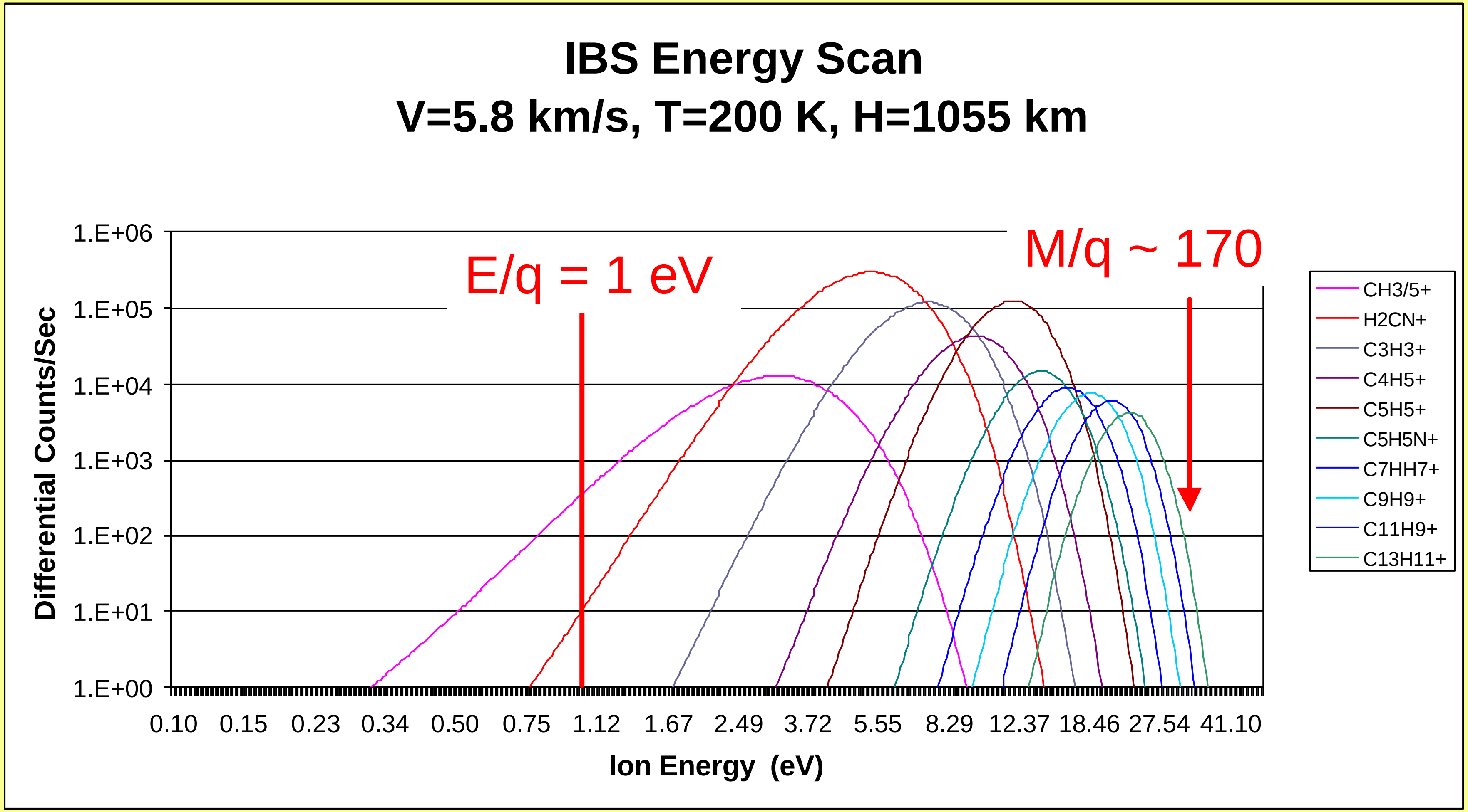


Combined spectra and analysis



O^+
NH_2^+
CH_4^+

IBS capability for mass → ¥



Comparison of CAPS with Voyager PLS and LECP

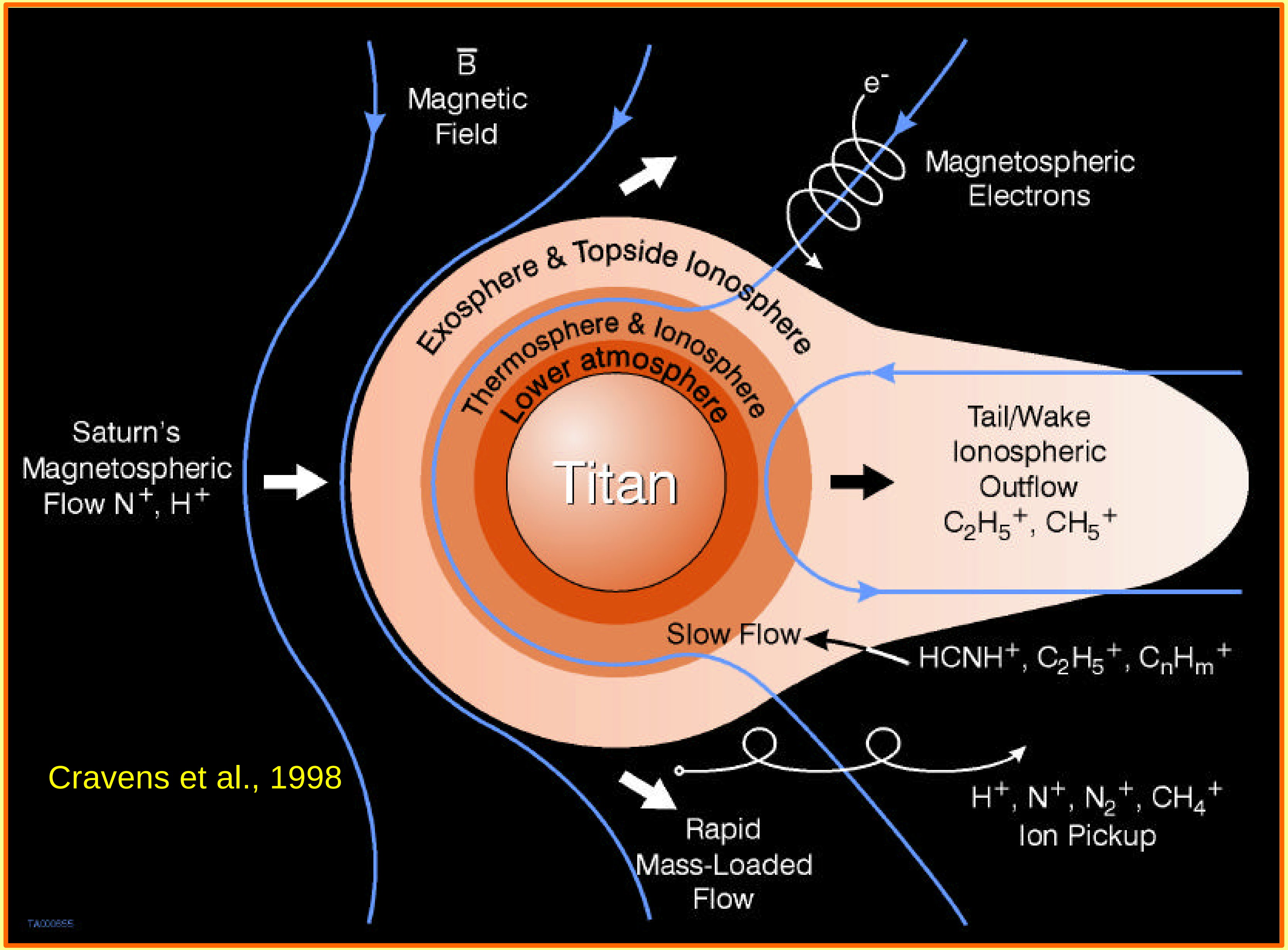
- CAPS fills Voyager's energy gaps:
  - **Voyager PLS and LECP energy range gaps:**
  - **6 to 22 keV (electrons)** **CAPS: 0.001 ~ 29 keV**
  - **6 to 28 keV (ions)** **CAPS: 0.001 ~ 50 keV**
- CAPS has an Ion Mass Spectrometer (IMS) (also INMS)
  - **Voyager did not have a mass spectrometer—relied on E/q**
  - CAPS: 1 ~ 100 amu @ M/ΔM ~ 60 (atomic); ~2600 (molecular)
- CAPS can control its pointing over ~2π sr
  - **PLS: 3 sensors on Earth-point (ions only)**
  - **PLS: 1 sensor into co-rotational flow (ions and electrons)**
- CAPS 2-D in 2s (electrons), 4s (ions), 3-D in ~180s
  - **PLS full measurement cycle 96 s for all species**

Cassini and Voyager: comparing encounters:

- Voyager 1: 1 Titan encounter
  - **V_F = 17.3 km/s => PLS got 7.4 electron distributions/R_T**
  - **C/A = 4394 altitude @ 1330 Saturn LT**

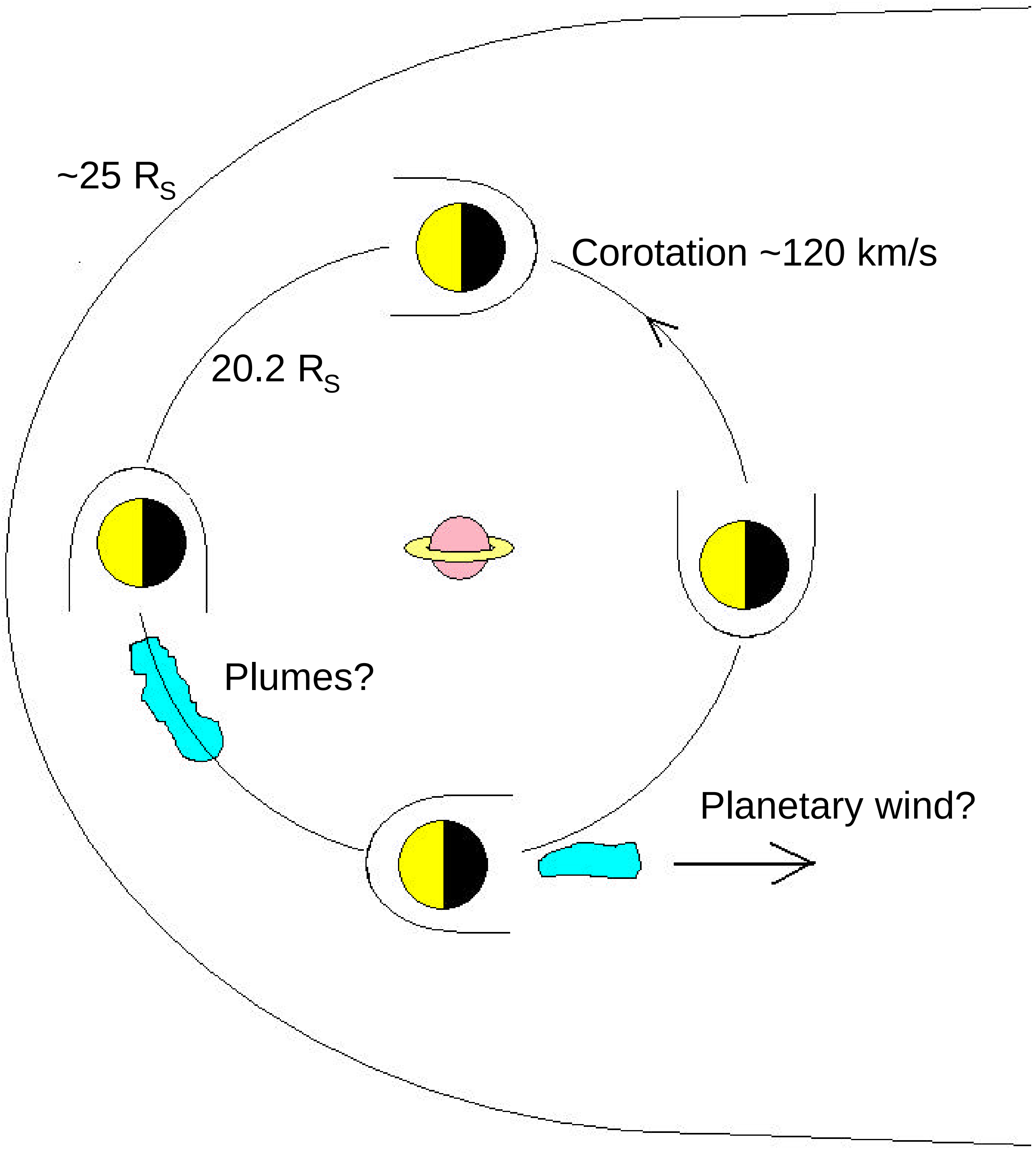
- Cassini: 44 Titan encounters
  - **V_F = 5.8 km/s => CAPS ELS gets 222 electron distributions/R_T**
  - **43 flybys are below Voyager 1's C/A altitude**
  - **25 are rated good to very good for CAPS observations**
  - **24 are at 950 km altitude over 13:30 – 21:00 LT:**

Our current understanding of Titan interactions



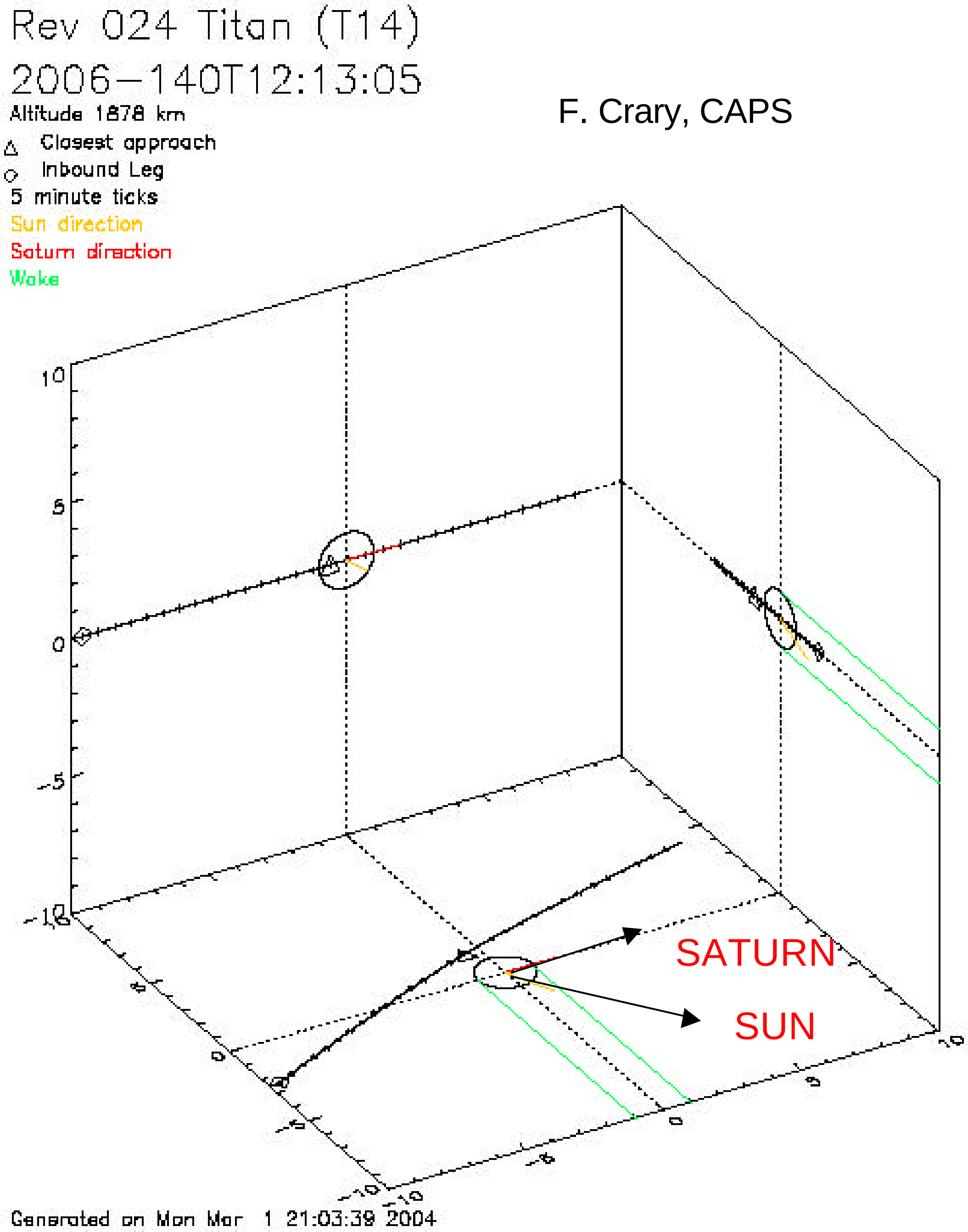
Cravens et al., 1998

Titan in Saturn's magnetosphere



Example of planning plot for Titan close encounter (T14)

04:24 Saturn LT



Key questions to which CAPS can contribute:

- What is the composition and chemistry of Titan's ionosphere?

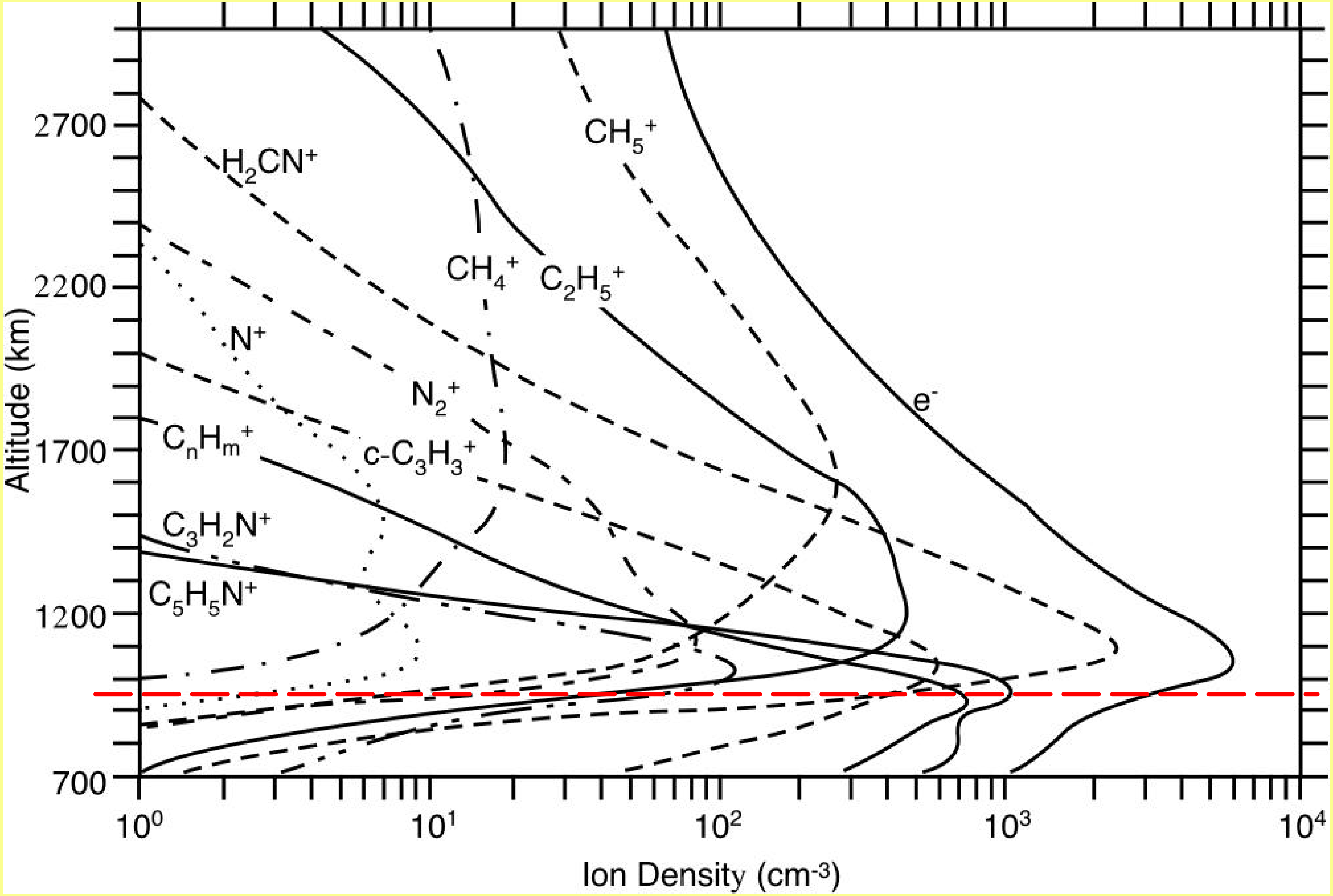
- What is the nature and morphology of Titan's induced magnetosphere?

- What does Titan contribute to Saturn's magnetosphere?

What is the composition and chemistry of Titan's ionosphere?

- Ionization and energy sources (ELS):
  - **Suprathermal (~ few 100's eV) electron precipitation**
  - **Photoelectron production**
  - **Total electron content (also RPWS Langmuir probe)**
- Composition (IMS)
  - **Complements INMS**
  - **Energized ion components (e.g., in flanks & tail) not seen by INMS**
  - **Separates isomers (e.g., N_2^+ vs. H_2CN^+)**
  - **Total elemental abundances**
- Ion velocities (IBS)
  - **Ion velocities to ~ 20 m/s cross-track**
  - **Ion composition to M ~ ¥**

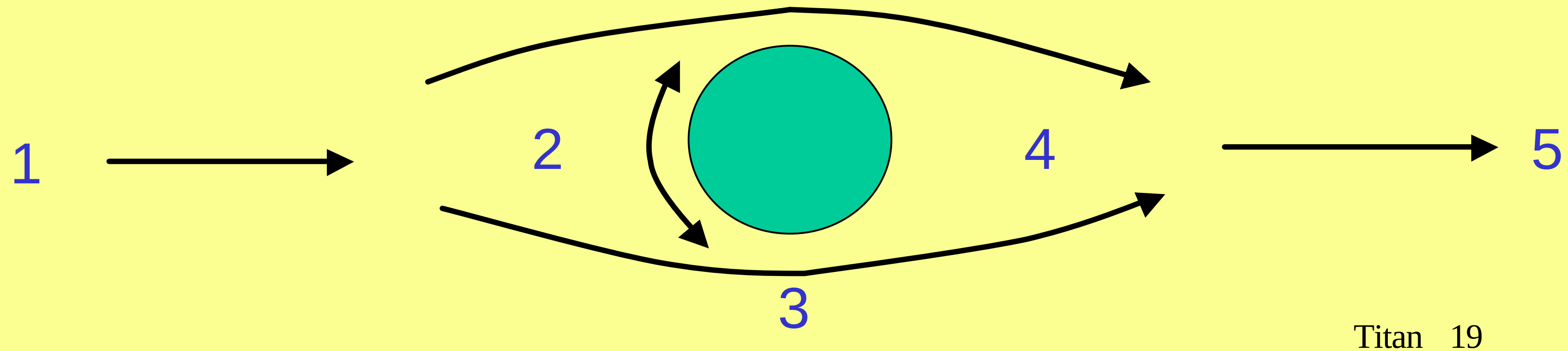
Complex chemistry with steep gradients (Keller et al., 1998)



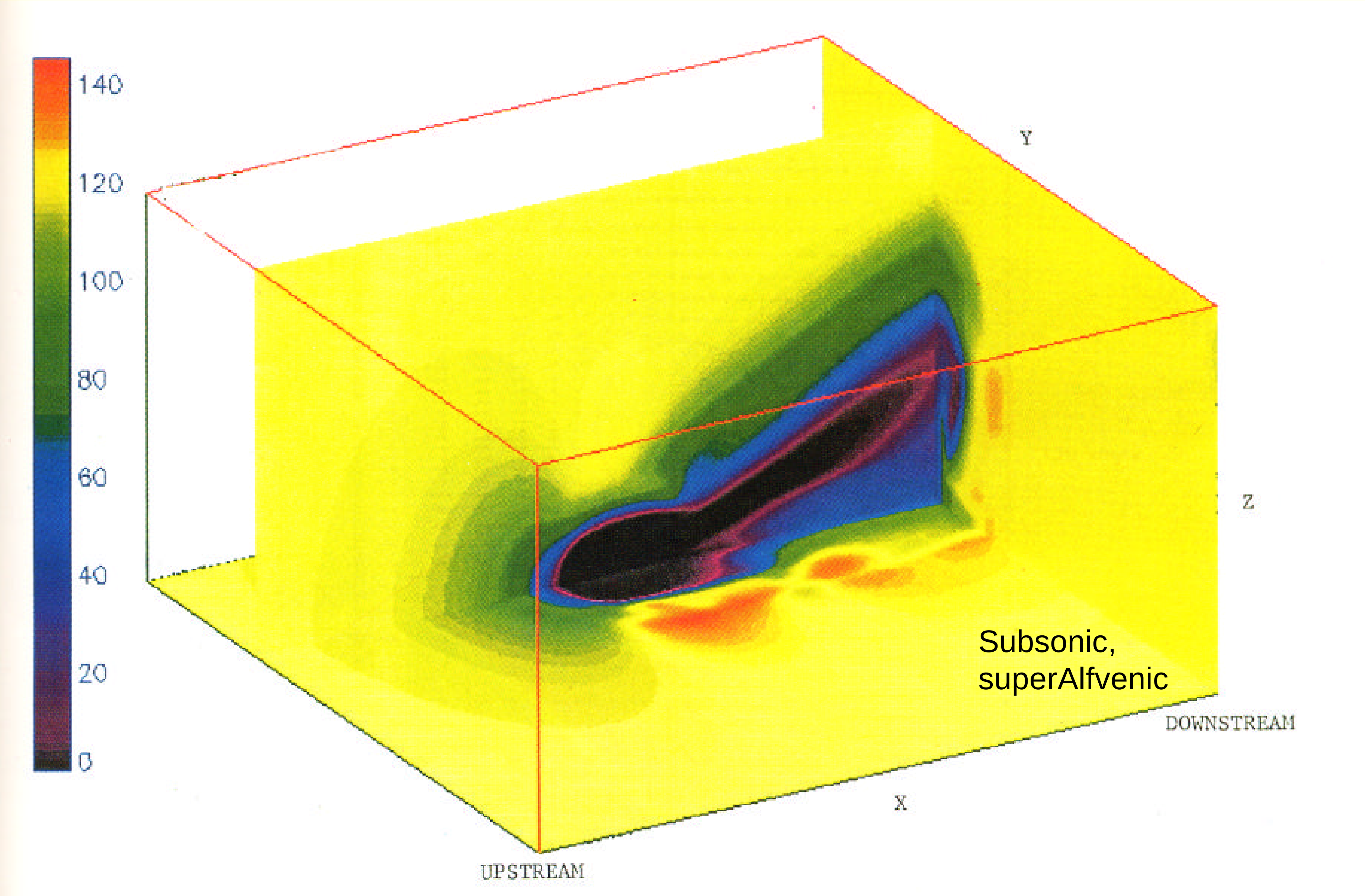
How is Titan’s magnetosphere formed?

Measurements are needed over a range of encounters:

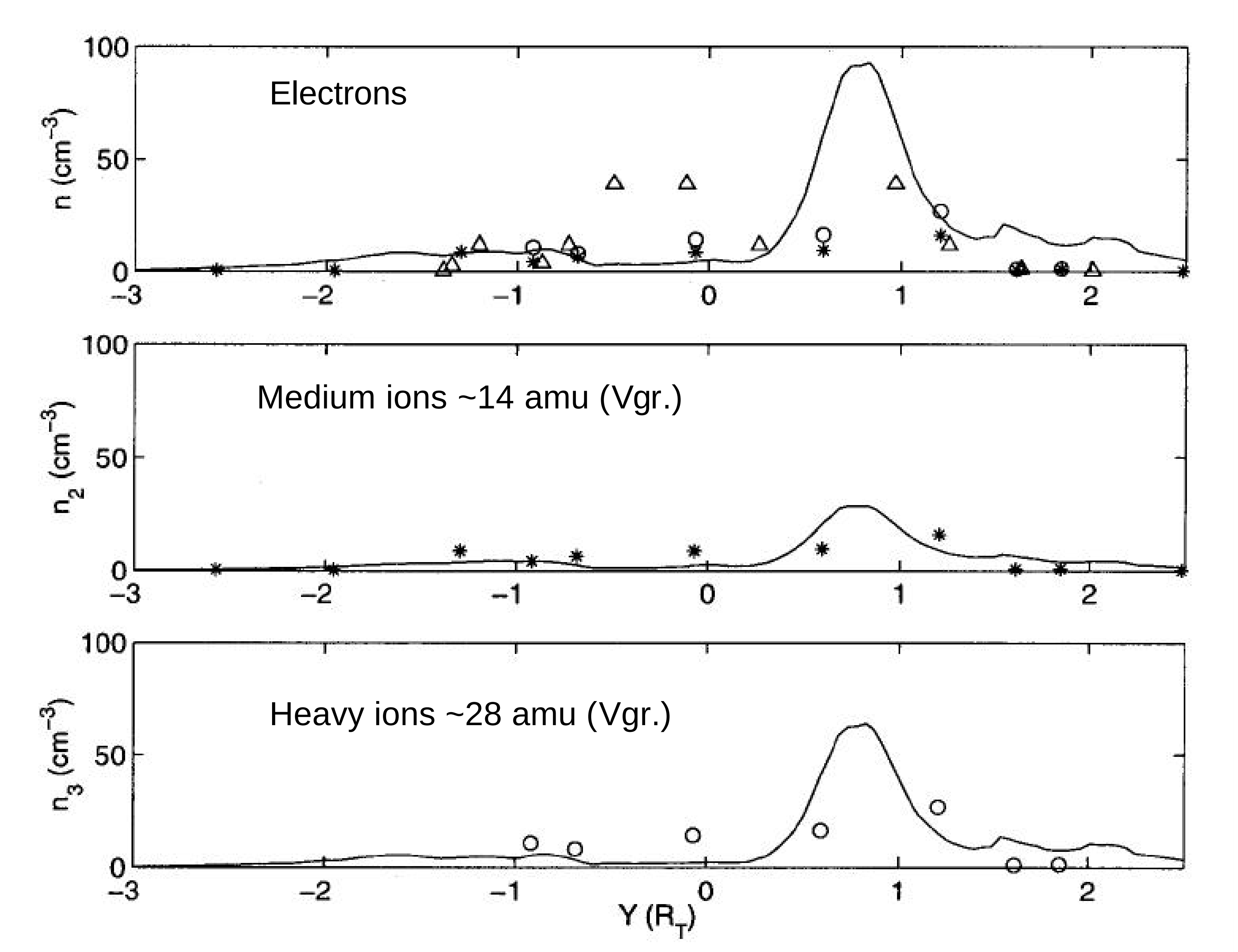
1. Far upstream: co-rotational flow (mass, momentum, energy)
2. Near upstream: mass loading by Titan’s exosphere
3. Near Titan: flow field around the ionopause obstacle
4. Near tail: structure, chemistry, mass loss
5. Far tail: ‘plume’ formation



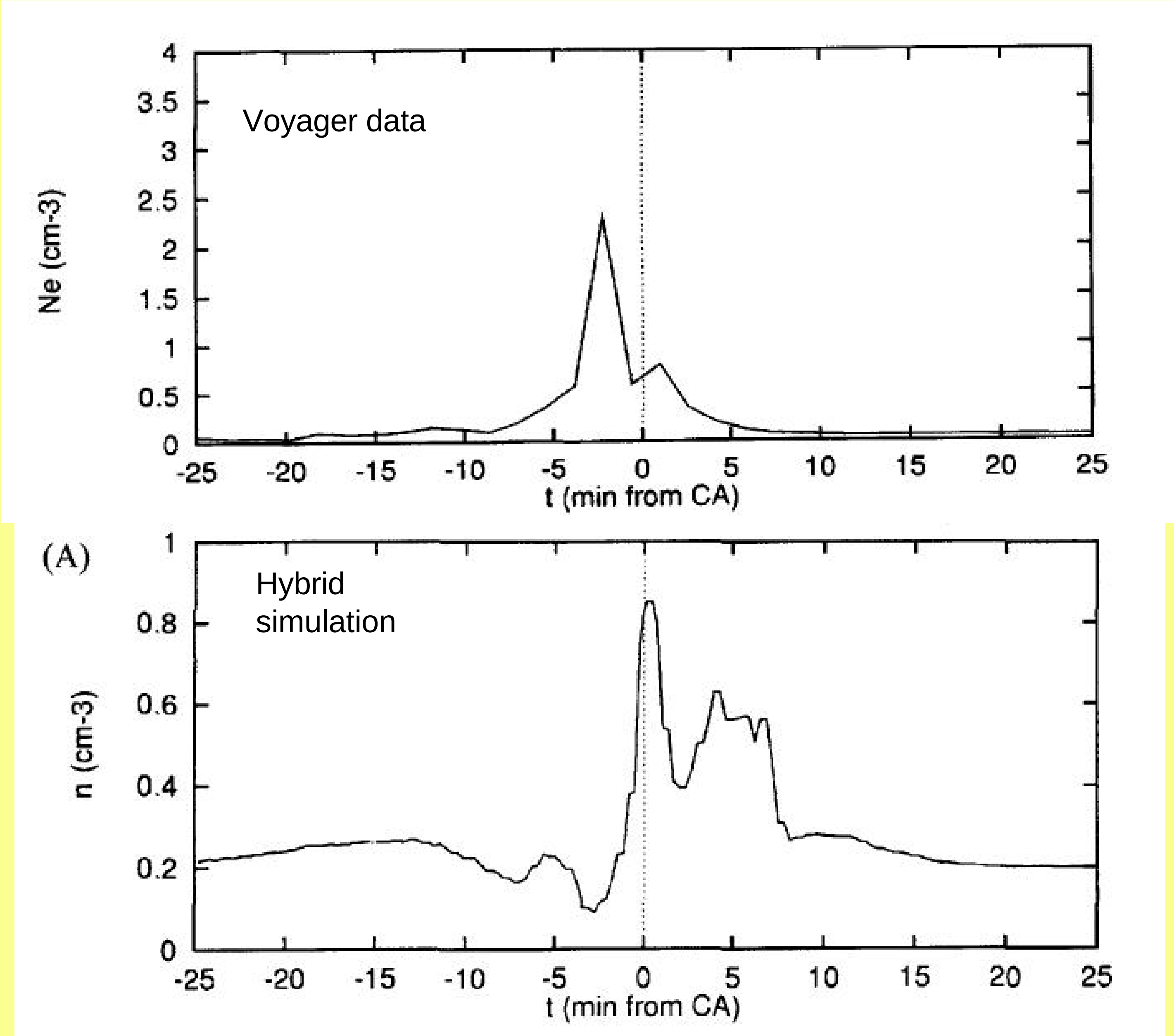
3-D MHD velocities (km/s) (Ledvina & Cravens, PSS, 46, 1175, 1998)



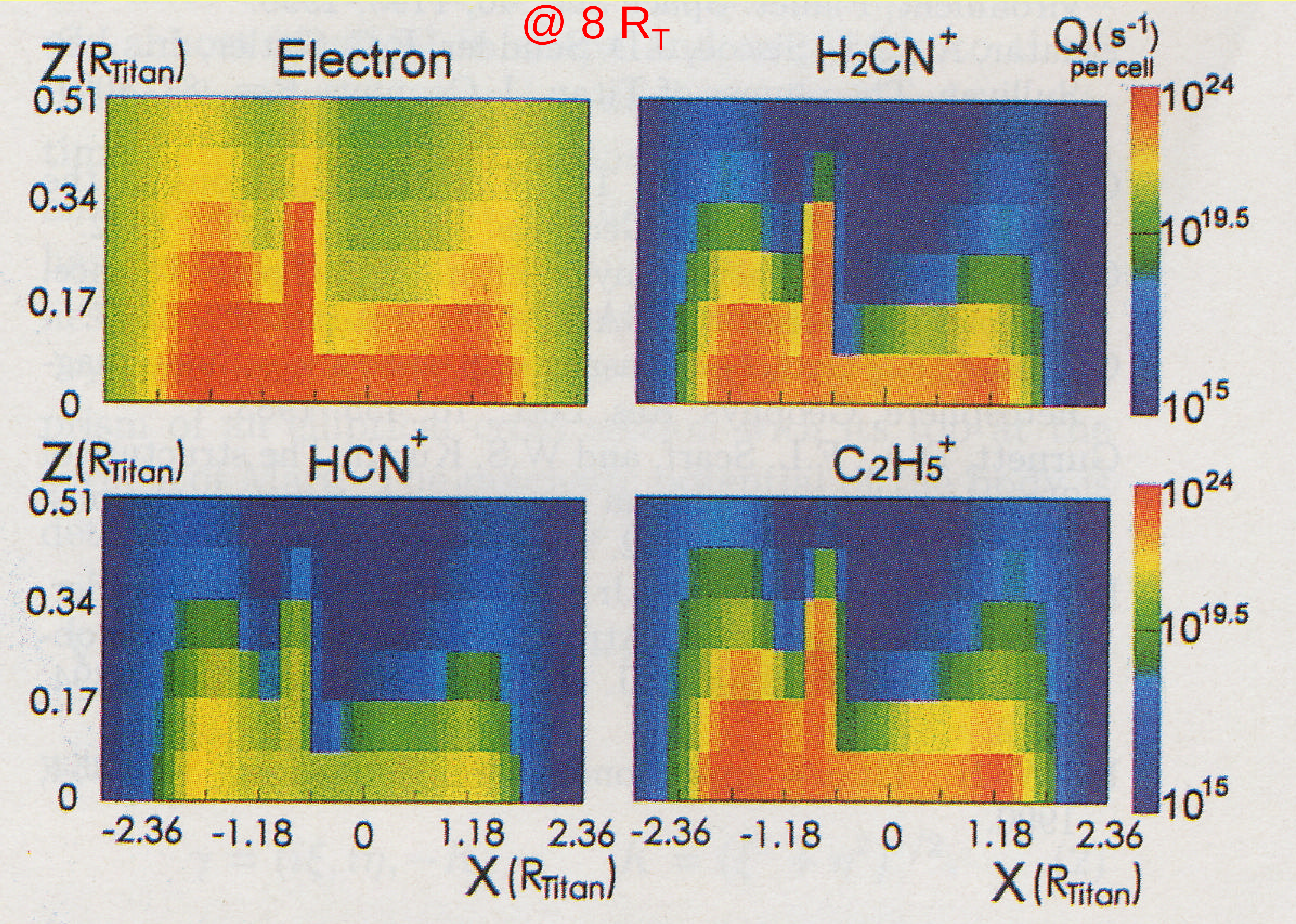
3-D MHD simulation—Voyager 1 trajectory (Nagy et al., JGR, 2001)



3-D hybrid simulation—Voyager 1 trajectory (Brecht et al., JGR, 2000)



Chemistry + 3-D MHD simulation (Chiu et al., GRL, 28, 3405, 2001)



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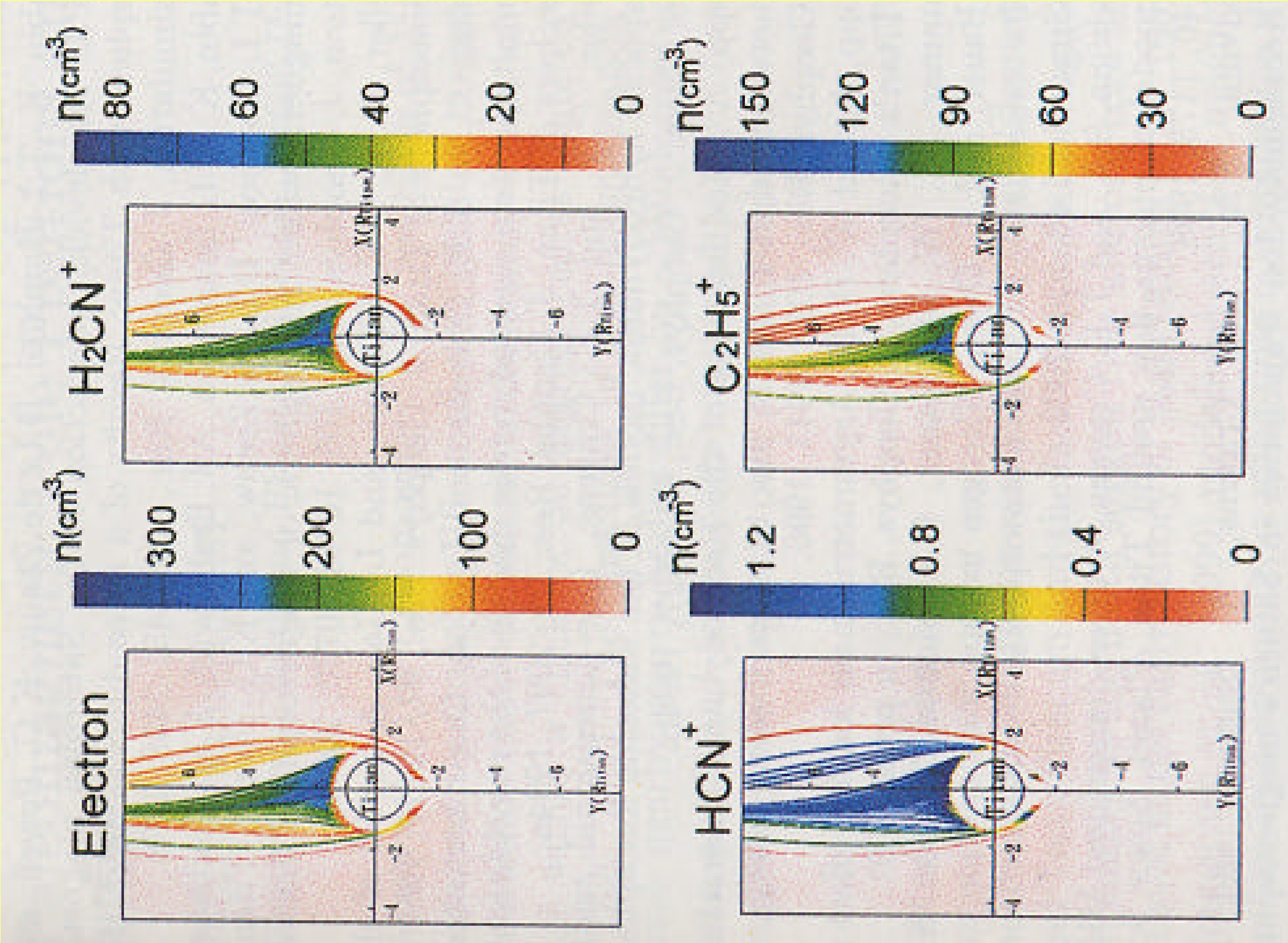
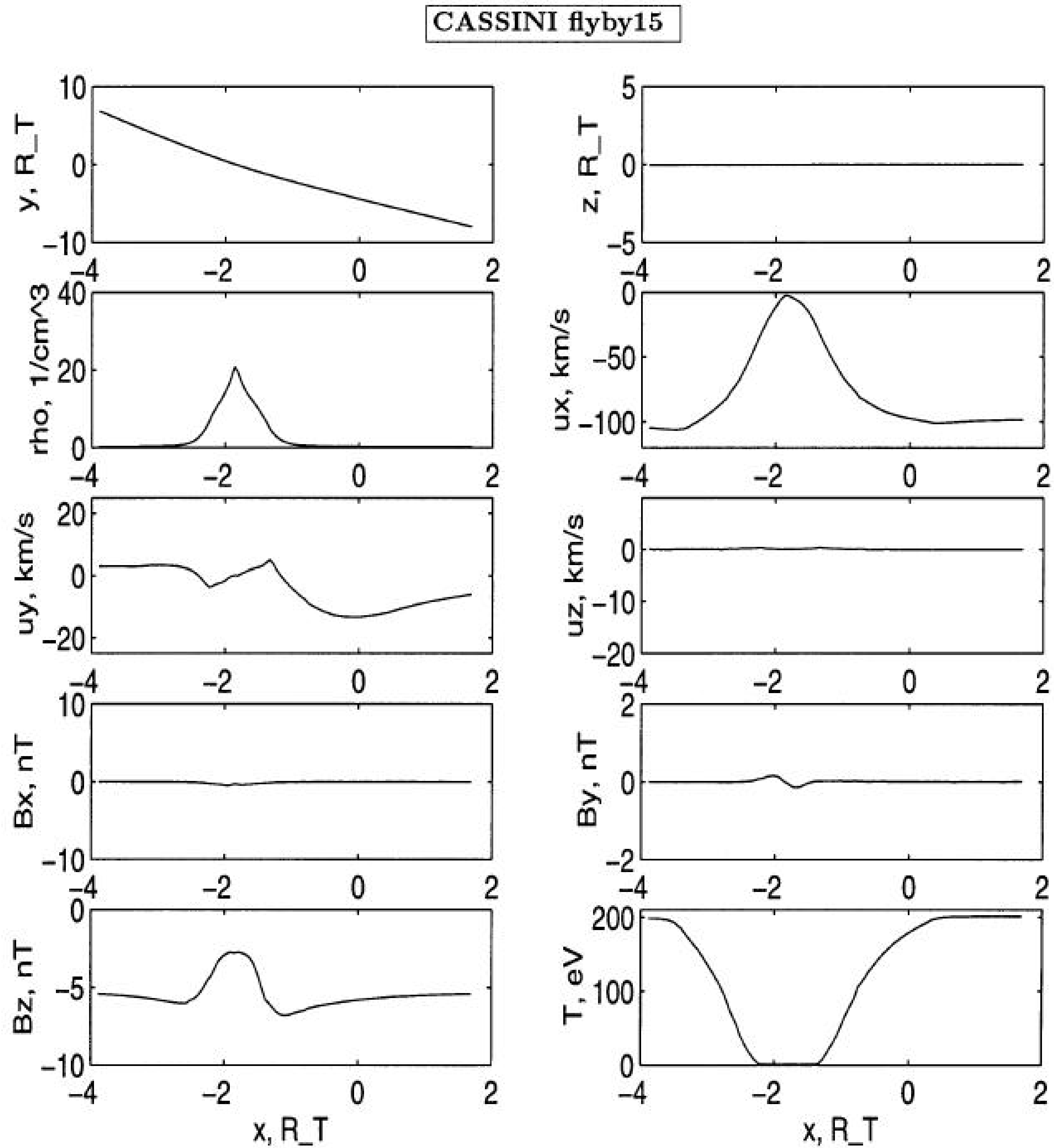


3-D MHD — Cassini trajectory

Titan encounter T15

1911 km c/a

(Kabin and Gombosi, UM, 1998)

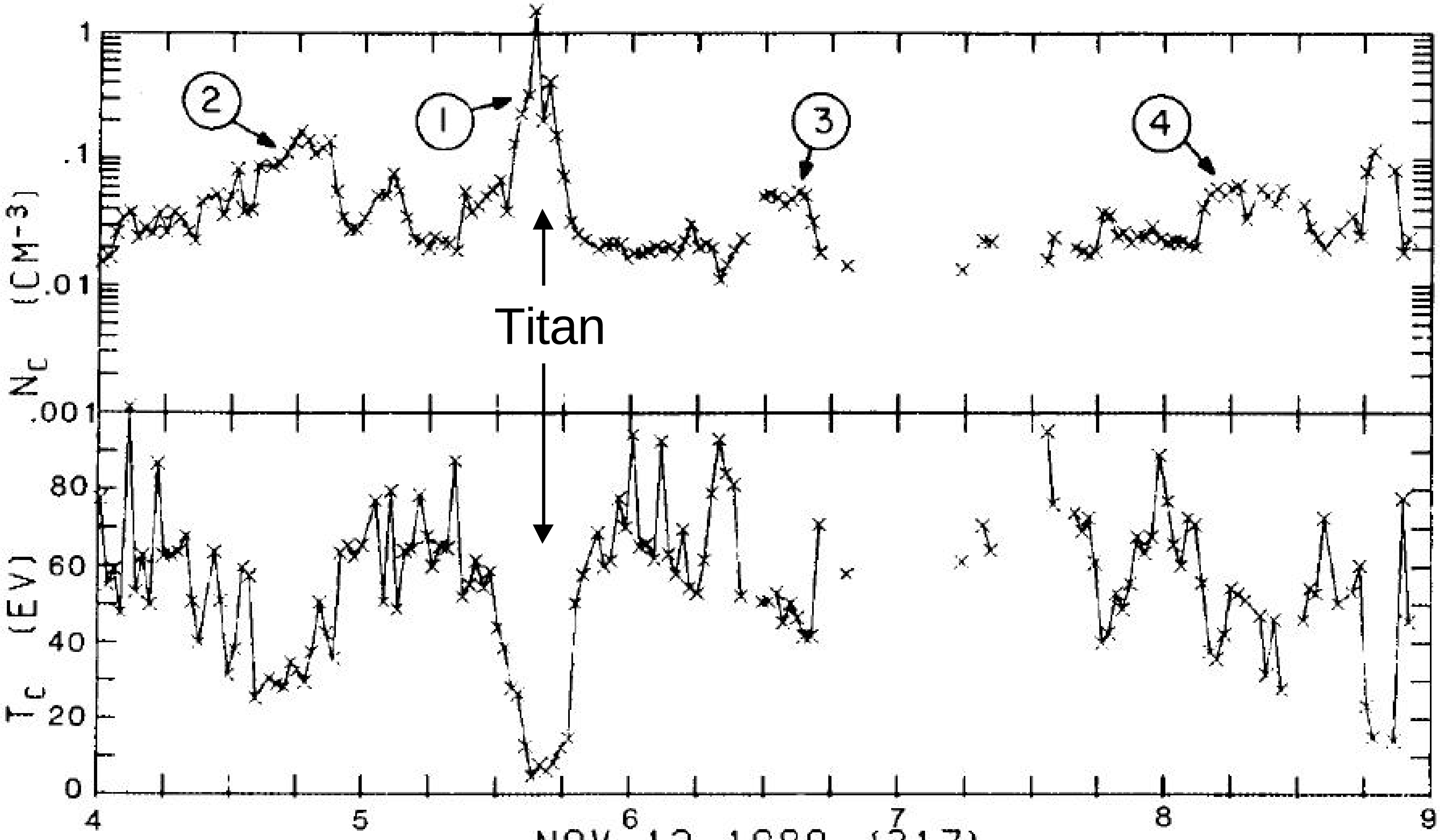


How does Titan affect Saturn's magnetosphere?

Titan's loss = Saturn's gain: three processes:

- Ion pickup and loss down Titan's wake (all species)
  - → **Mass loading of co-rotational flow**
    - →**Relationship of co-rotation shear to aurora?**
- Atmospheric sputtering (primarily N, N_2) *(Sittler et al., 2004)*
  - → **Ionization of sputtered atmosphere**
    - → **Acceleration by pickup**
      - → **Radial diffusion and acceleration**
        - → **Surface weathering of inner icy satellites**
          - → **Pickup of sputtered surface products**
- Escape of torus ions as planetary wind *(Goertz, 1983)*
  - → **Return as accelerated plasma in substorms (Earth analog)?**

Voyager 1, electrons, Eviatar et al, 1982



Eviatar et al., *JGR*, **87**, 8091, 1982

Conclusions

1. There is no lack of Titan models, but they are constrained in most cases by only one set of measurements (Voyager 1).
2. Thus the models have never been tested, except for self consistency, over a range of conditions (mass-momentum-energy inputs, LT, solar wind conditions, etc.)
3. Since many models already exist there should be a tidal wave of scientific productivity after the first few Titan encounters.
4. There will be more than enough data to work on until > 400th Huygens' anniversary.