The Plasma Environment of Pluto - *Collisional Effects (Pluto Workshop Boulder, CO - August 2014)*

T. E. Cravens

(University of Kansas)

Types of Solar Wind Interaction

- Earth-like (strong intrinsic magnetic field acts as obstacle to solar wind flow)
- Venus-like (ionospheric thermal pressure)
- Comet-like (ion pick-up and mass-loading)
- {“real” interactions are a “mixture” of the archetypical interaction types}
- The *solar wind interaction with Pluto* is probably quite *comet-like* although some Venus-like *ionopause* could be possible.

Single fluid momentum equation

$$\rho \left[\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}\right] = -\nabla p + \mathbf{J} \times \mathbf{B} + \rho \mathbf{g} - \rho \bar{\nu} (\mathbf{u} - \mathbf{u}_n) - P_i m_i (\mathbf{u} - \mathbf{u}_n)$$

$$\mathbf{J} \times \mathbf{B} = \frac{1}{\mu_0} (\nabla \times \mathbf{B}) \times \mathbf{B} \qquad = -\nabla \left(\frac{B^2}{2\mu_0}\right) + \frac{1}{\mu_0} \mathbf{B} \cdot \nabla \mathbf{B}$$

Venus-like Ionopause. Ionospheric thermal pressure balances magnetic/solar wind pressure. Ionopause is located where:

$\rho_{sw} u_{sw}^2 \approx B^2 / 2\mu_0 \approx n_e \, k \, T_e$ (ionosphere).

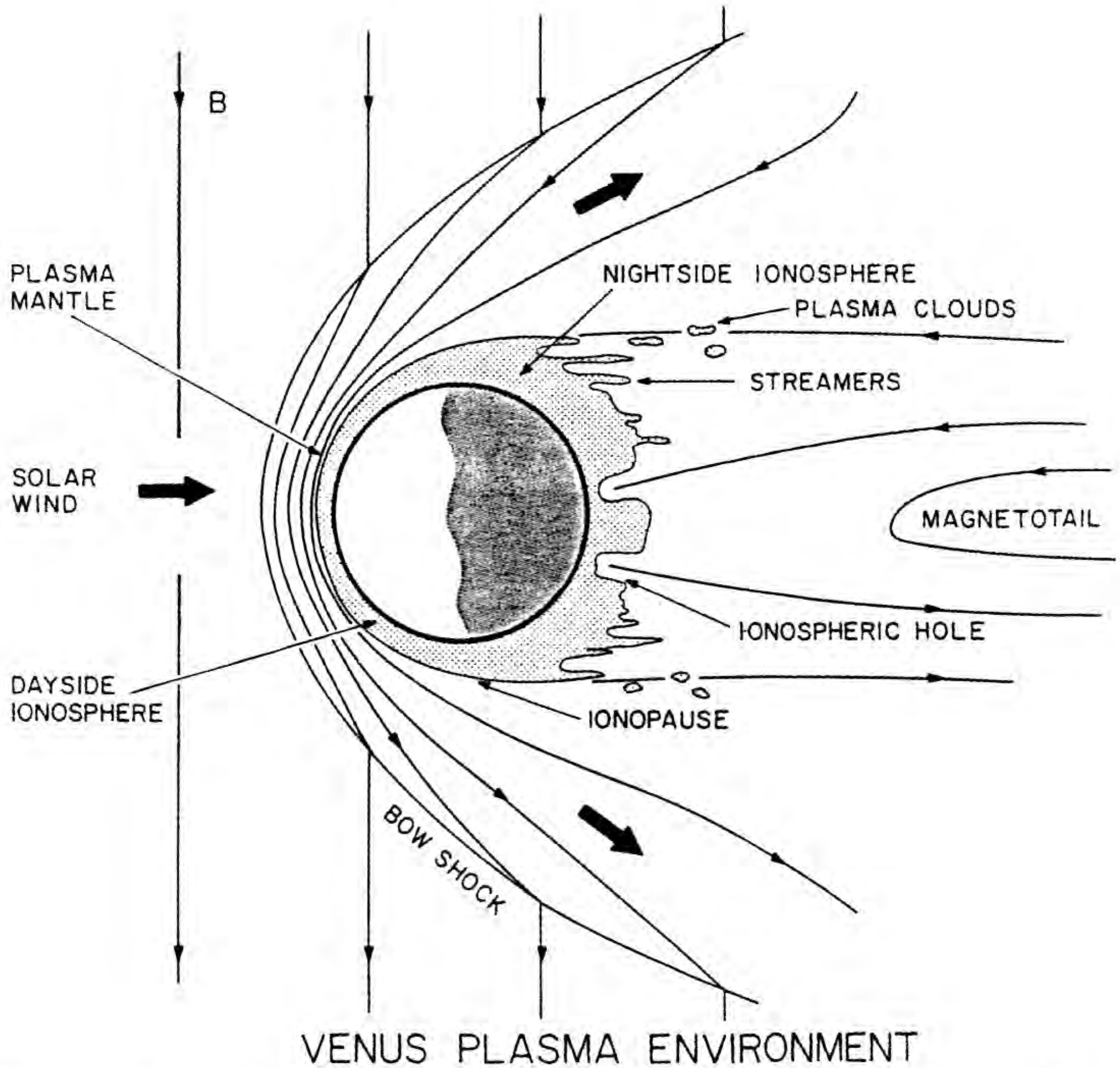


Figure 1. Schematic of the solar wind interaction with Venus. Interplanetary magnetic field lines are shown as are the bow shock and ionopause surfaces.

Schematic of

VENUS-LIKE SOLAR WIND ATMOSPHERE INTERACTION

Ionospheric thermal pressure acts as main obstacle to the solar wind.

Dynamic pressure - thermal - magnetic and - ionospheric thermal.

Magnetic field strength and electron densities measured by instruments onboard Pioneer Venus Orbiter

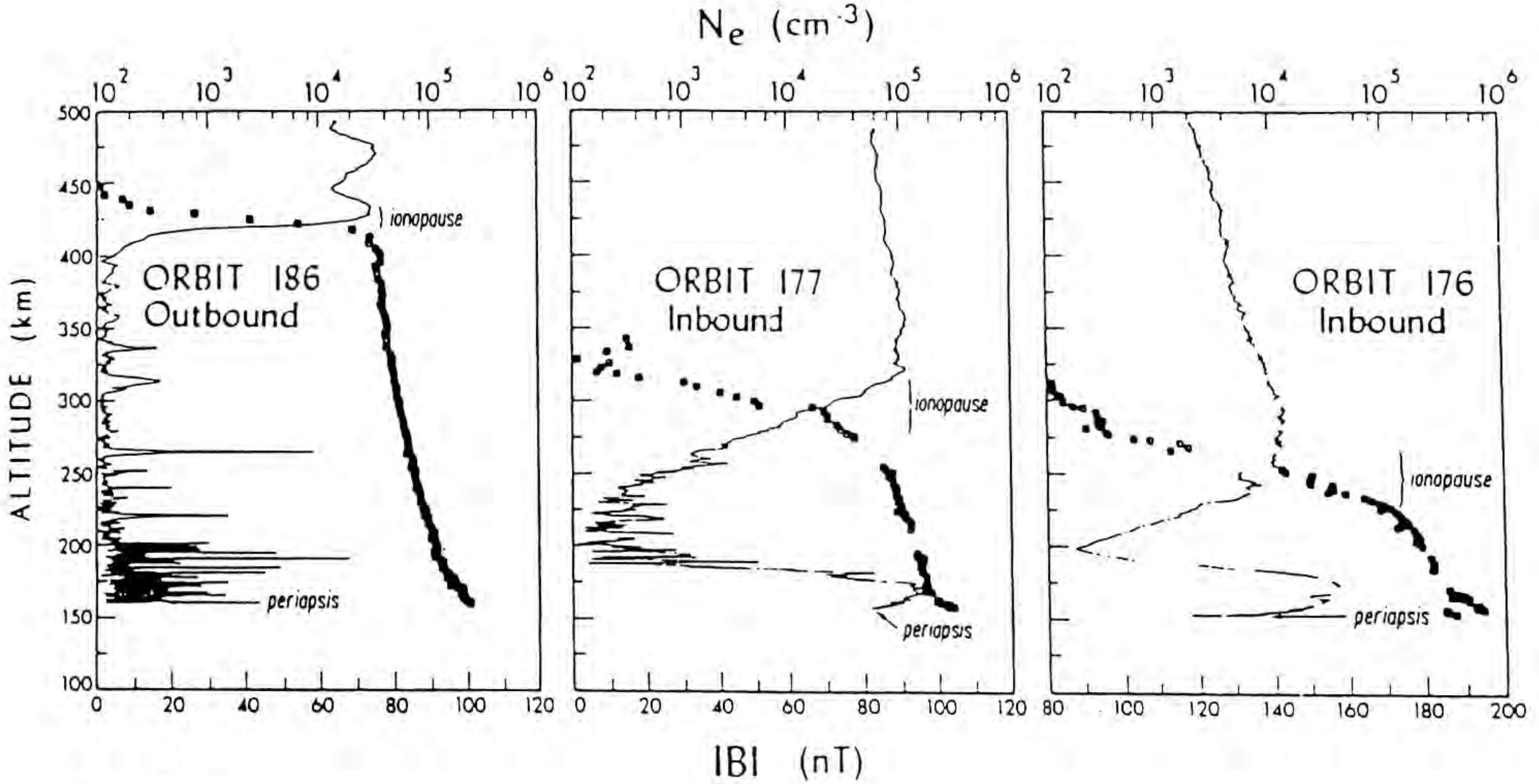


Figure 2. Measured magnetic field strength (Pioneer Venus Orbiter magnetometer) and measured electron density (Langmuir probe) in the ionosphere of Venus (figure from Russell and Vaisberg 1983).

Thermal pressure in ionosphere balances magnetic pressure in the magnetic barrier (also ≈ solar wind dynamic pressure)

Comet G-Z

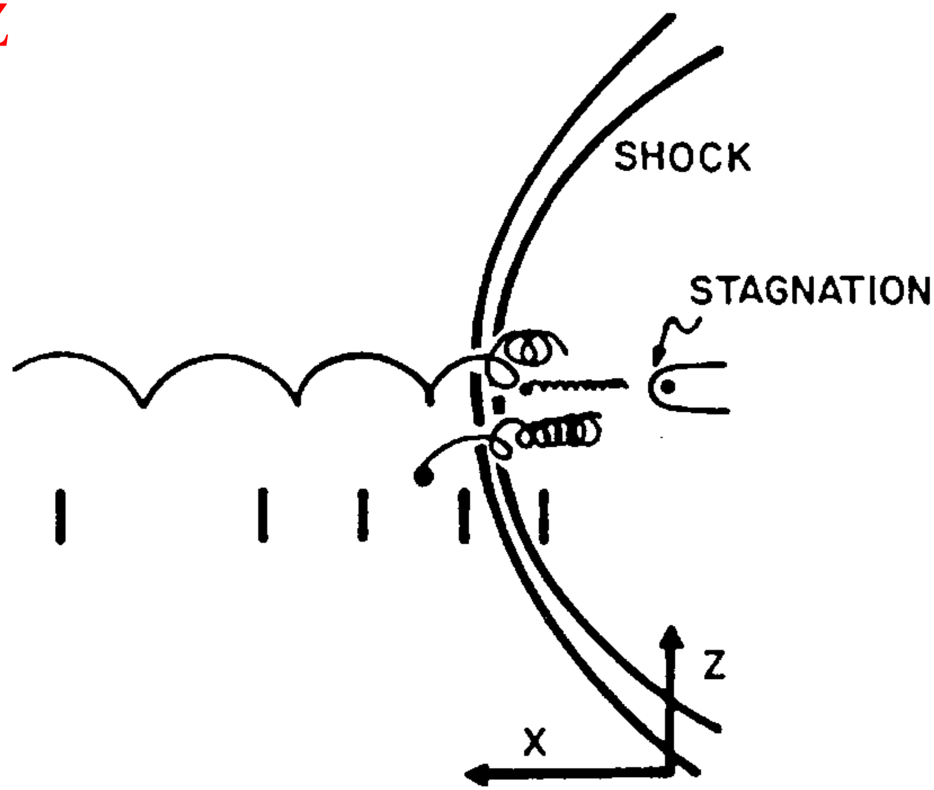
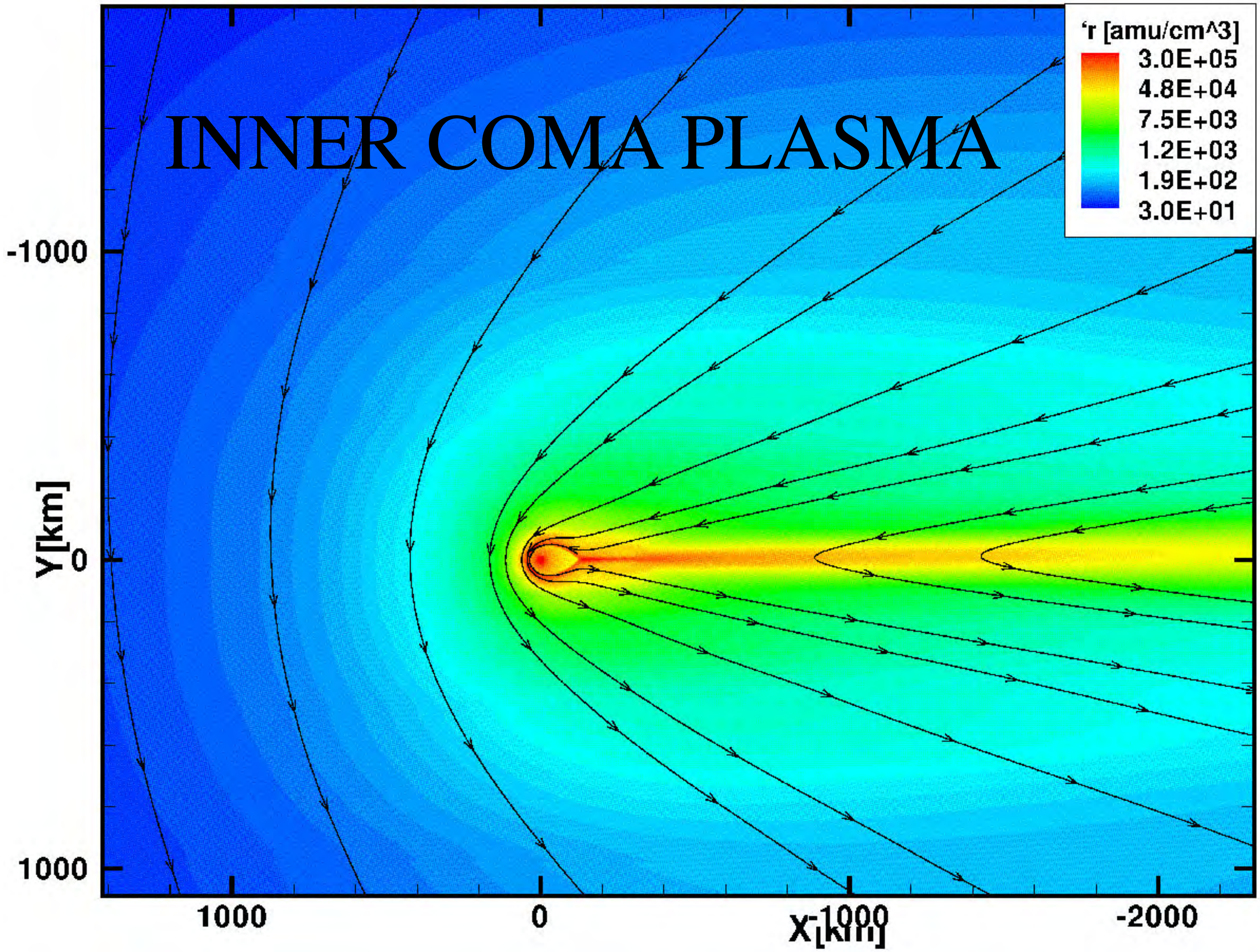


Figure 5: Schematic of the solar wind interaction with comet Giacobini-Zinner. Three calculated H_2O^+ trajectories are shown, 5 sampling bin locations are also shown. (from Cravens 1986)



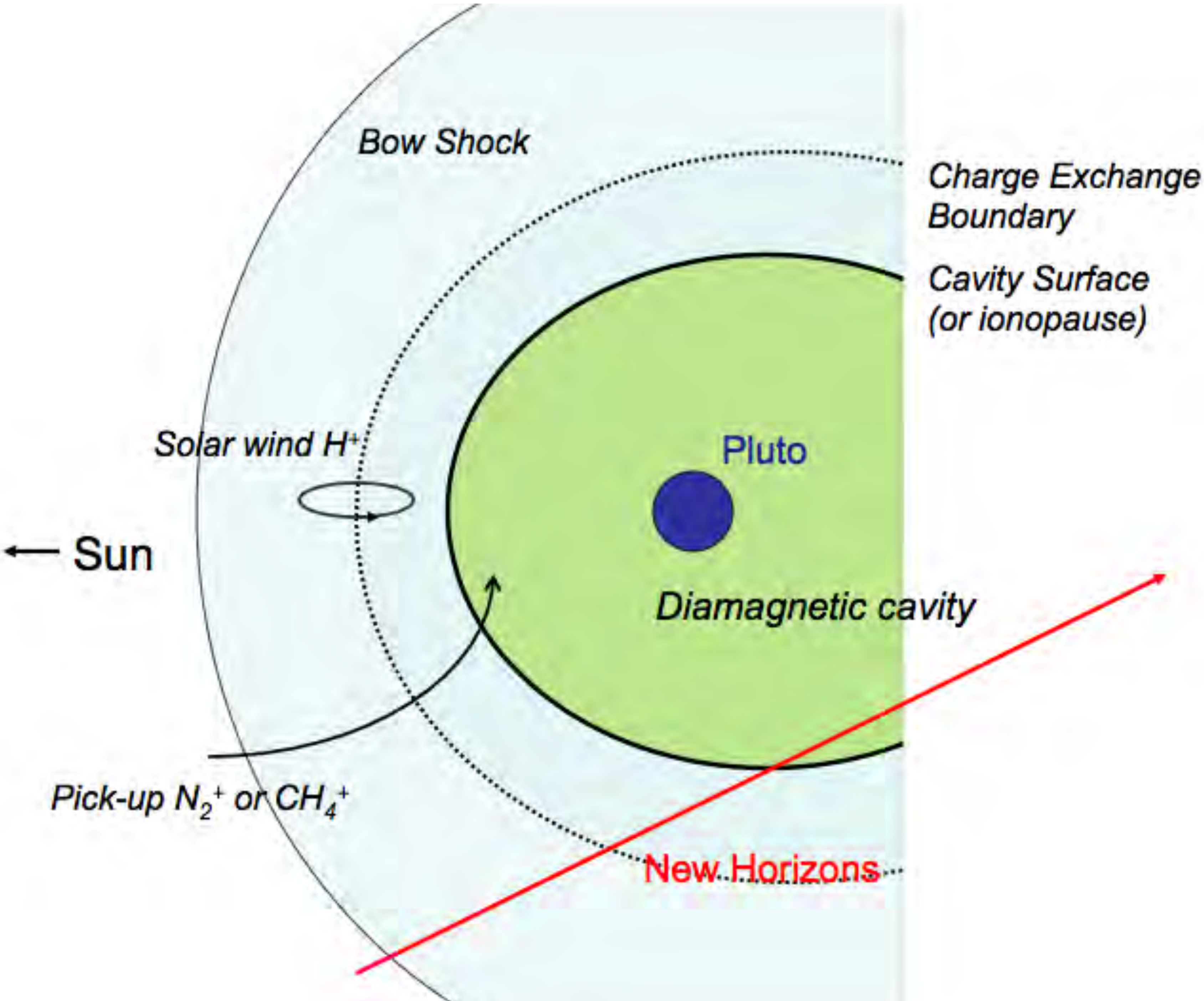
Michigan MHD model of comet CG at 1.3 AU

K.C. Hansen et al. (2007)   Also - hybrid simulations---

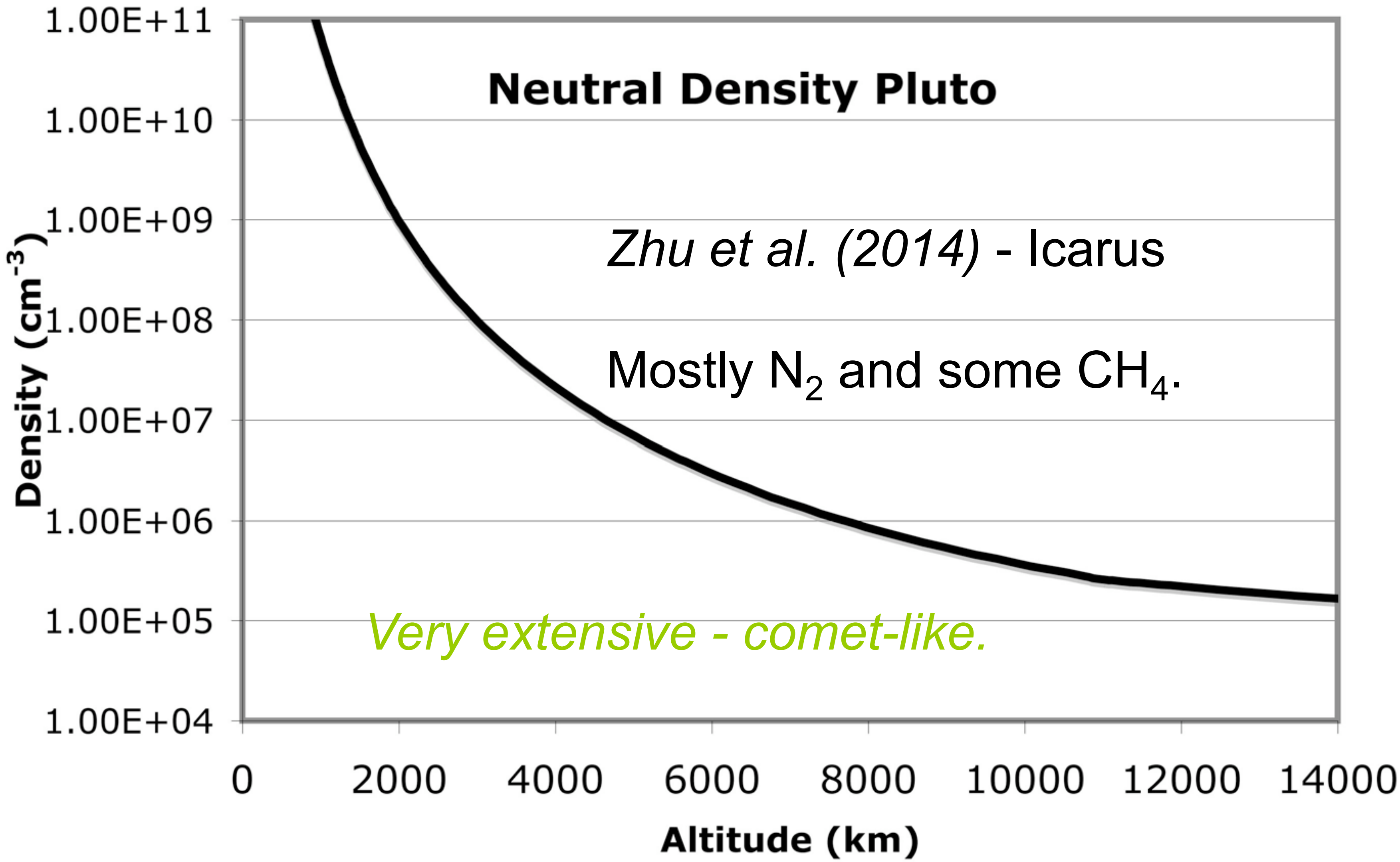
Bagdonat et al. (2004)

Plasma Boundaries - what form do they take for very weak comets (or Pluto)

- *Bow Shock* - width about 1 heavy ion gyroradius (3 x10^5 km) --> bow wave?
- *Cometopause* - gradual transition (charge exchange collisions).
- *Pile-up Boundary* (magnetic barrier).
- *Diamagnetic Cavity and/or ionopause boundaries* - width of about 100 km. Do they exist and if they do can they be seen?

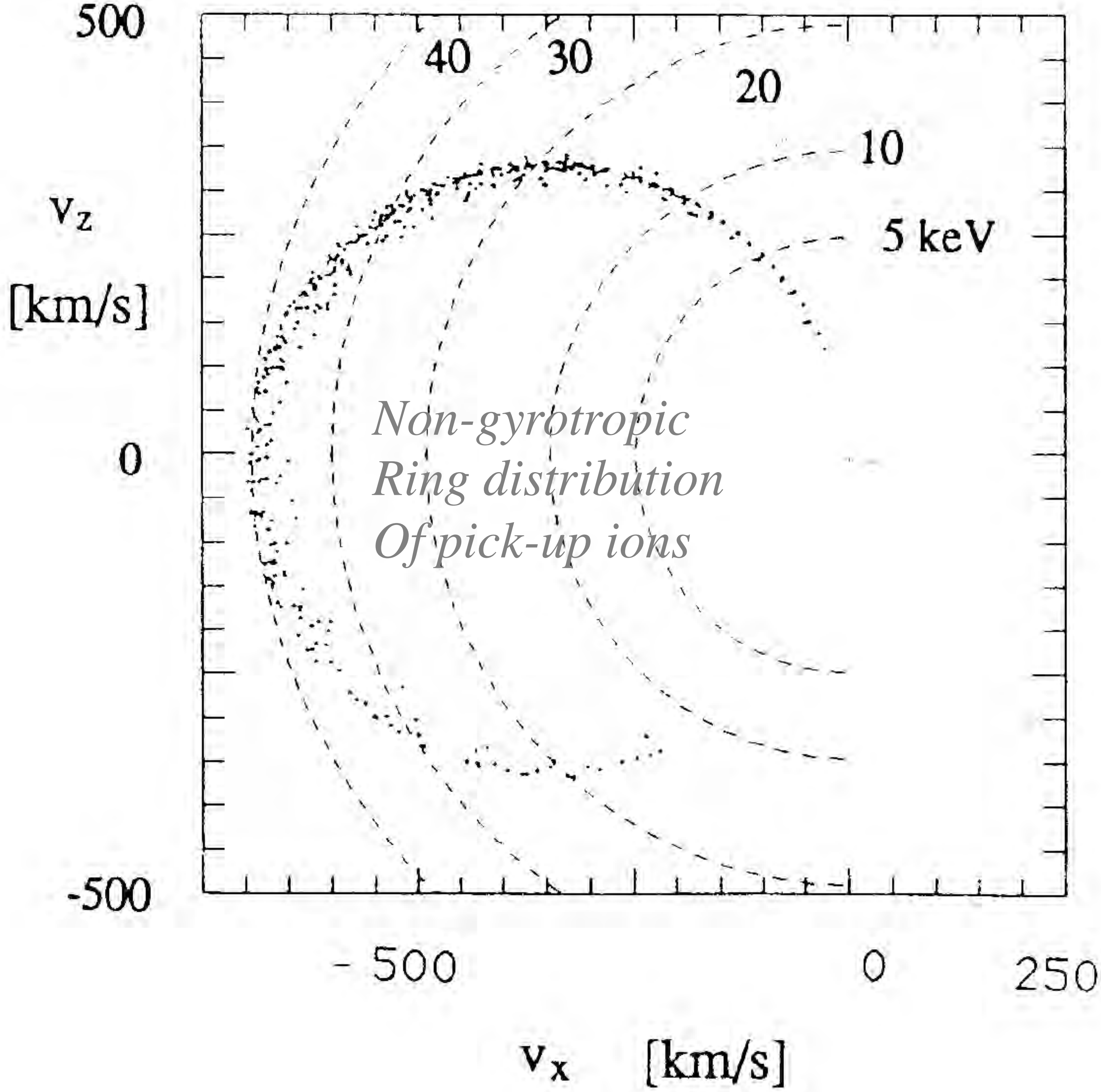


Cravens and Strobel (2014) (Icarus)


Neutral Density Pluto
Zhu et al. (2014) - Icarus
Mostly N2 and some CH4.
Very extensive - comet-like.
Density (cm-3)
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
0
2000
4000
6000
8000
10000
12000
14000
Altitude (km)

Plasma Sources (photoionization by solar radiation)

- $h\nu + N_2 \text{--->} N_2^+ + e$
- $\text{--->} N^+ + N + e$
- $h\nu + CO \text{--->} CO^+ + e$
- $C^+ + O + e$.....
- $h\nu + CH_4 \text{--->} CH_4^+ + e$
- $CH_3^+ + H + e$
- ....



Predicted CH_4^+ Pick-Up Ion Distribution Function -

PLUTO
But also weak comets

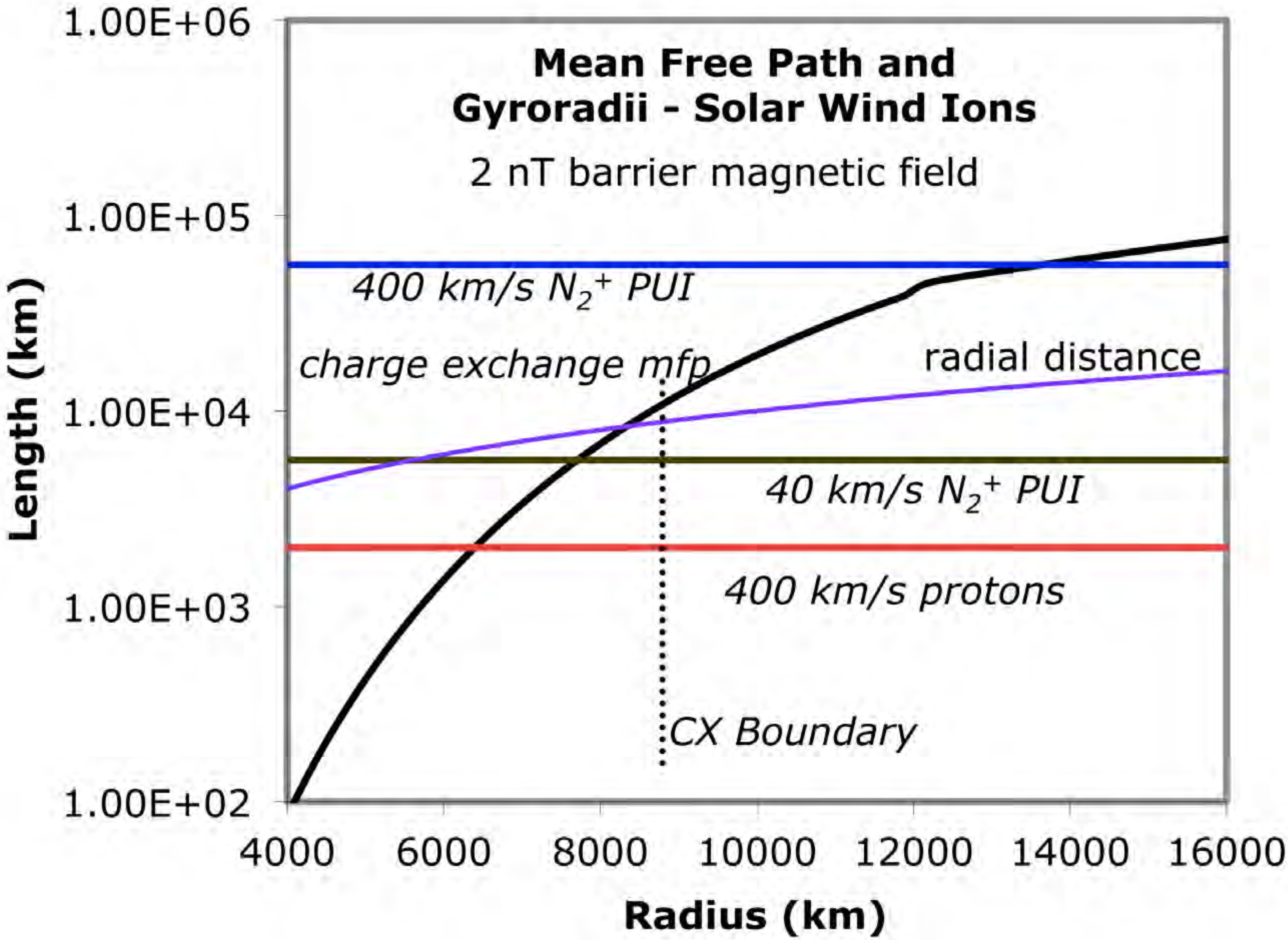
From Kescskemety and Cravens (1993)

Cometopause - *collisional effects*

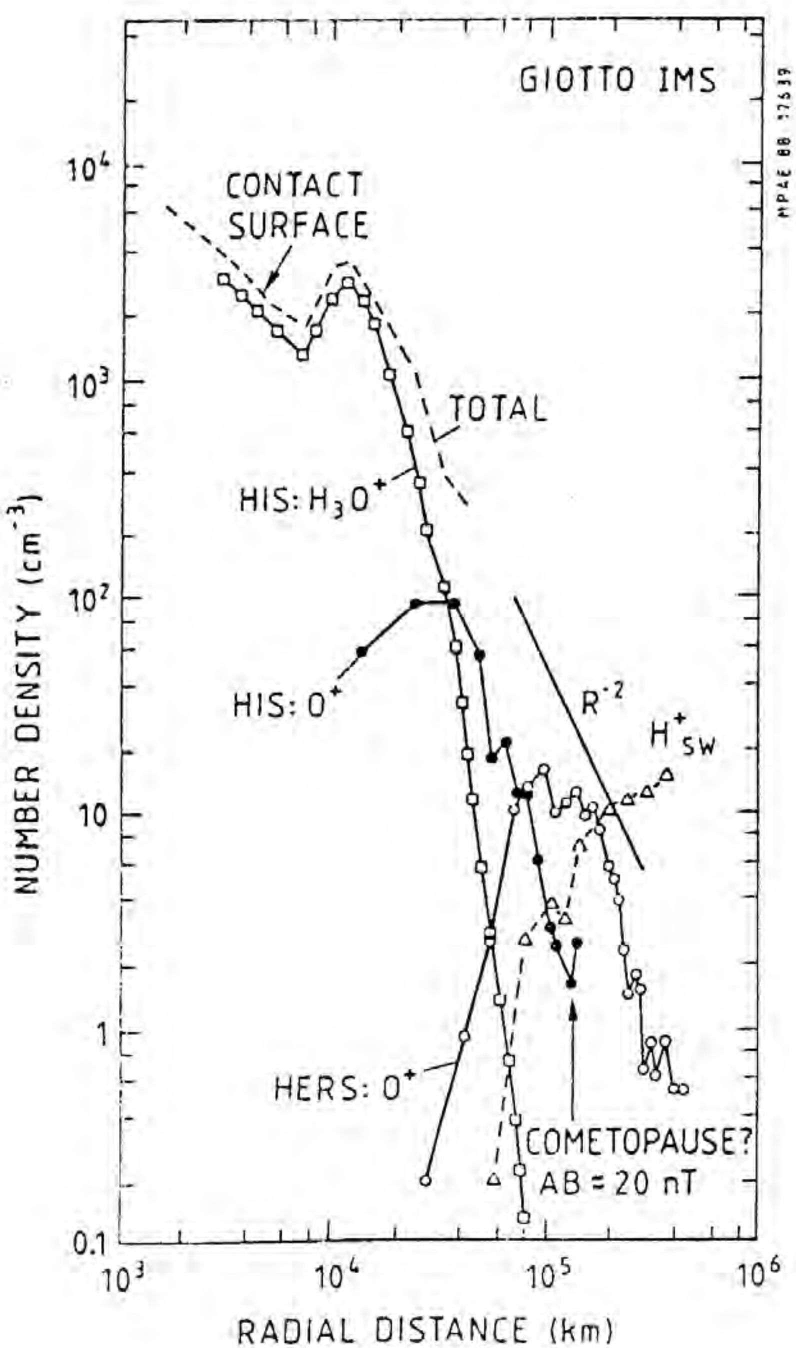
- Location where hot solar wind ions or cometary pick-up ions disappear due to charge exchange with cometary neutrals.
- $H^+ + M \text{ ----> } H_{fast} + M^+$
- Momentum is removed from the flow and a new colder PUI is created.
- The cometopause distance (that is, collisional effects) depends on the cross section and the gas production rate. (expression not shown)
- $R_{cometo} / R_{shock} \approx 0.1$ (≈ 2000 km comet CG - *8000 km Pluto*)
- Note the solar wind proton gyroradius -- ≈ 300 - 1000 km for CG (*pluto - 2000 km*).

Inner Coma Plasma Environment How developed at comet CG?

- Ion chemistry (ion-neutral reactions and electron-ion dissociative recombination)
- $h\nu + H_2O \text{-->} H_2O^+ + e$
- $H_2O^+ + H_2O \text{--->} H_3O^+ + OH$
- $H_3O^+ + e \text{---->} H_2O + H$
- Full chemistry is much more complex.
- Colder thermal electrons (thermalized coma photoelectrons). When and where does this happen for comet CG?
- Diamagnetic cavity where neutral outflow colliding with plasma is balanced by external magnetic pressure. Does it exist for comet CG (magnetometer and Langmuir probe)?
- **REPLACE comet CG with Pluto and this remains valid. But the chemistry is different also.**



Where do collisions first become important? (r ≈ 8000 km)

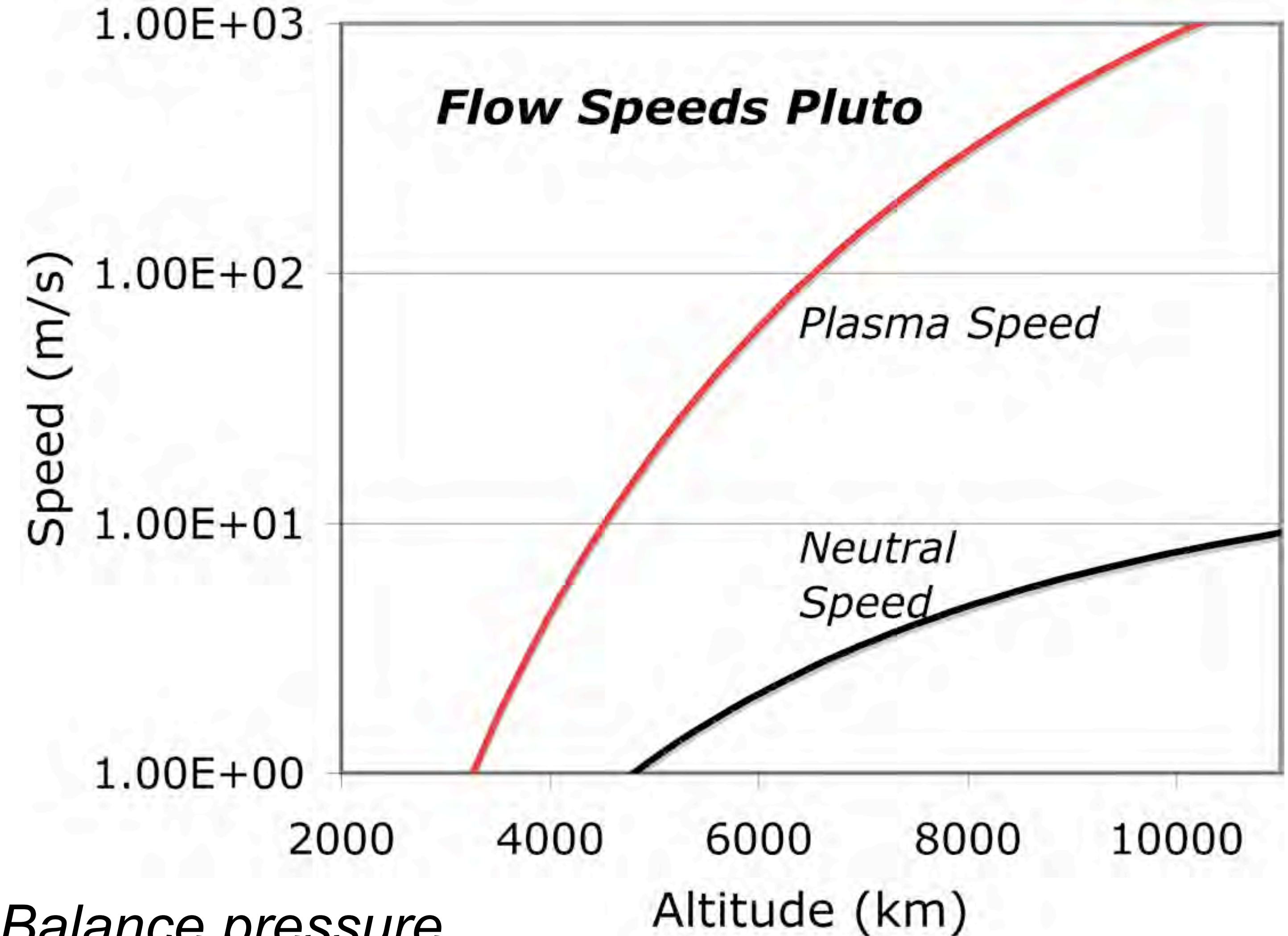


Comet Halley
Ion densities

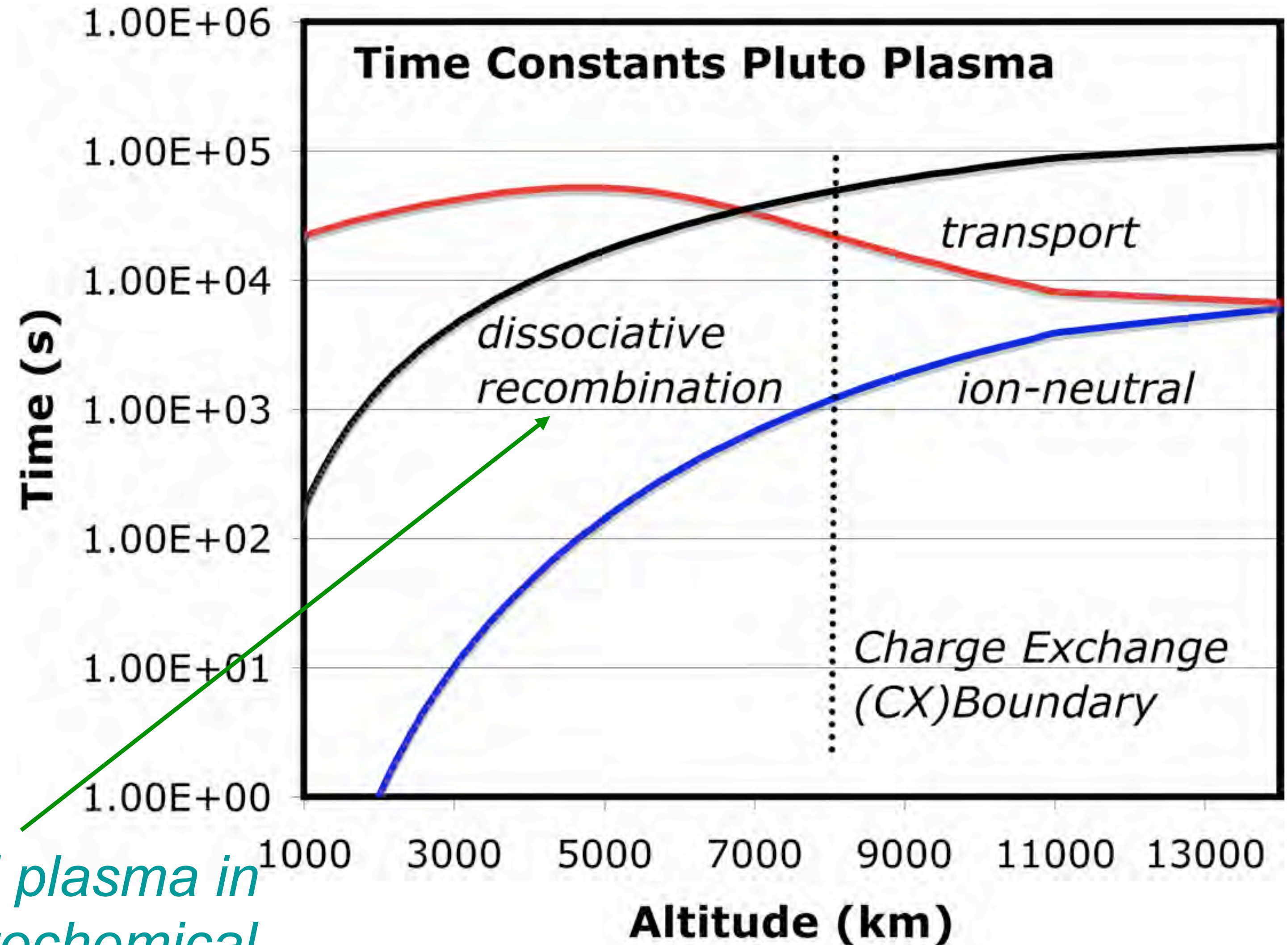
Giotto IMS

Balsiger et al., 1986; Ip(1989)

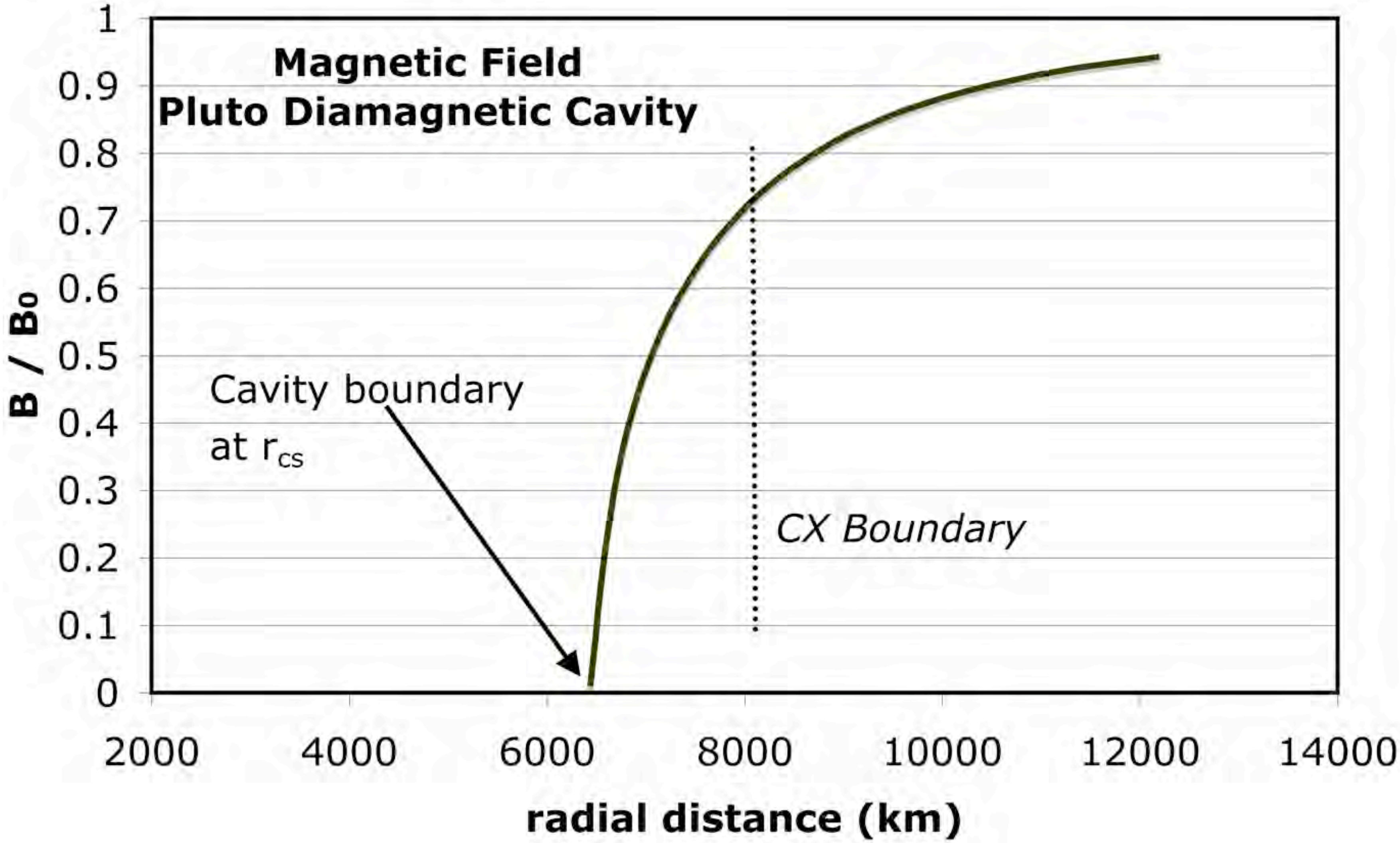
Indication of CX effects



Balance pressure against ion-neutral collisions for slow plasma.



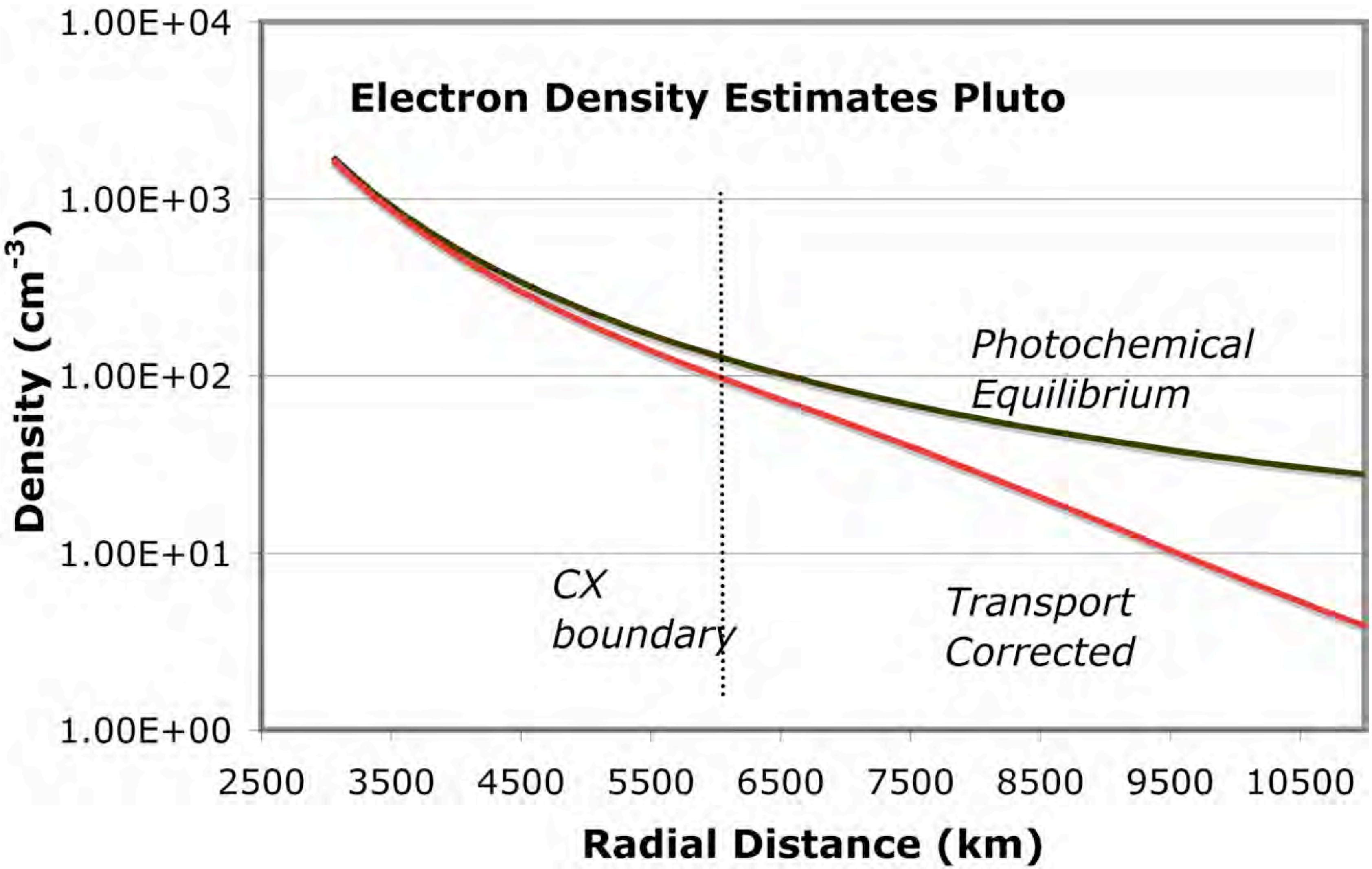
Cold plasma in Photochemical Equilibrium



Balance of outward ion-neutral drag and inward
Solar wind (I.e., magnetic) pressure - diamagnetic cavity

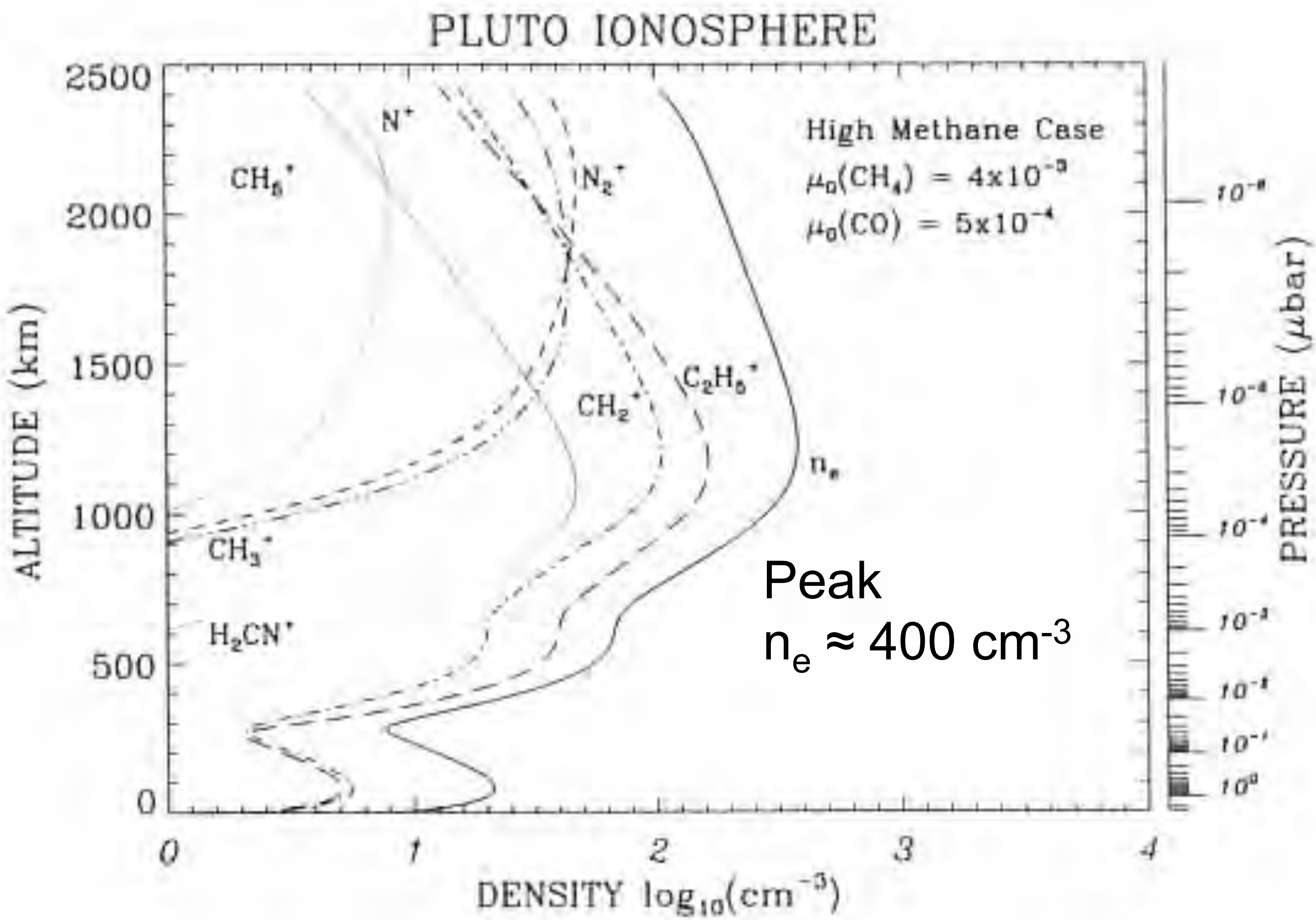
Ionospheric Chemistry (high methane)("Titan-like")

- N_2^+ + CH_4 ---> CH_3^+ + H + N_2
- N_2^+ + CO ---> CO^+ + N
- N^+ + CH_4 ---> CH_3^+ + NH
- ----> $HCNH^+$ + H_2
- CH_4^+ + CH_4 ---> CH_5^+ + CH_3
- CH_3^+ + CH_4 ---> $C_2H_5^+$ + H_2
- $C_2H_5^+$ + HCN ----> $HCNH^+$ + C_2H_4
- $HCNH^+$ + e ----> HCN + H
- $C_2H_5^+$ + e ----> C_2H_4 + H ……
- ….
- ***$C_2H_5^+$, $HCNH^+$, CH_5^+ dominated ion composition***
- (More later)



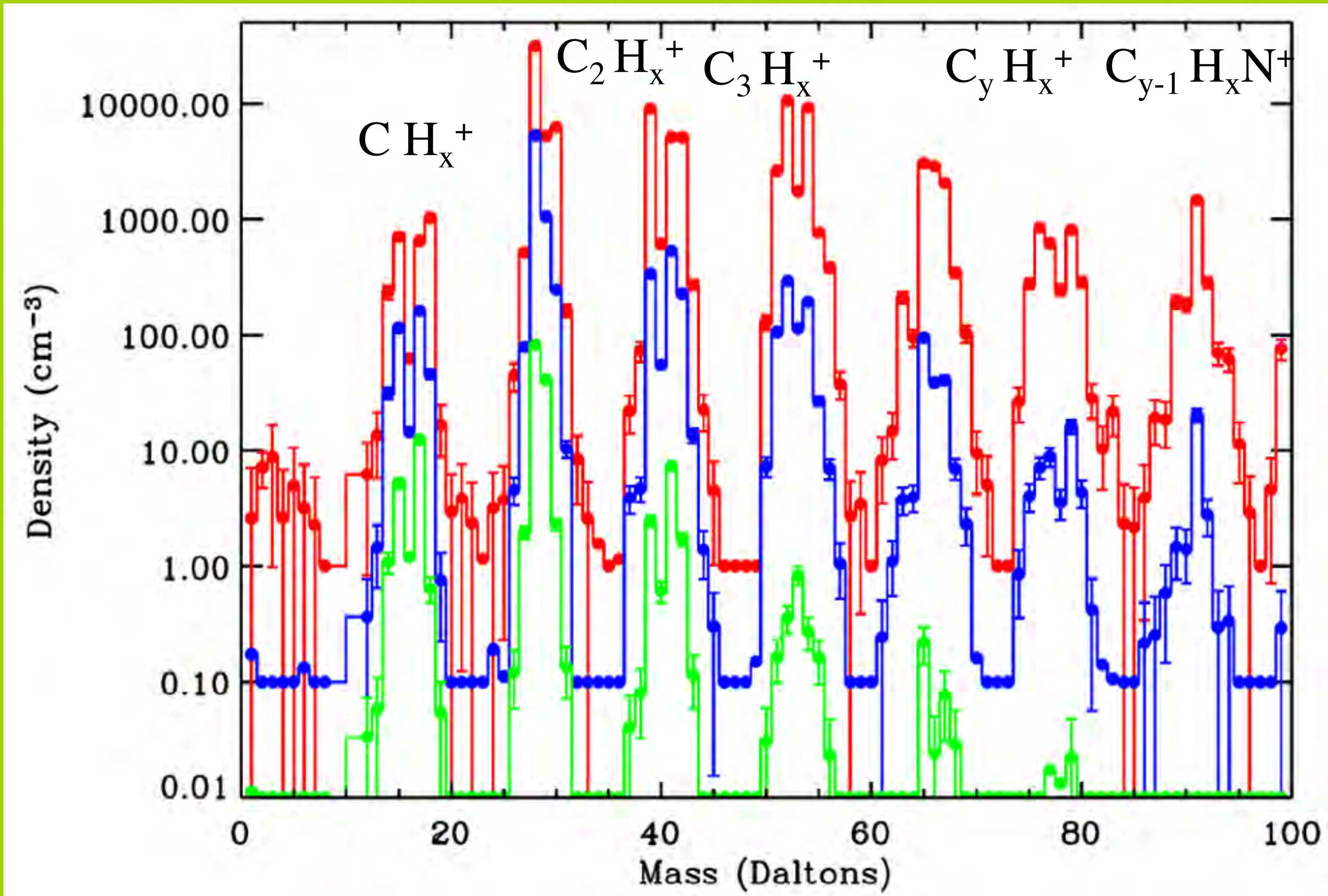
Electron Density Estimates Pluto
Density (cm-3)
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
2500
3500
4500
5500
6500
7500
8500
9500
10500
Radial Distance (km)
Photochemical Equilibrium
CX boundary
Transport Corrected

High Methane Ionosphere (Summers et al., 1997)



Peak
$n_e \approx 400\ cm^{-3}$

INMS T5 ion spectra for 3 altitude ranges (red near CA)



TITAN Ion Composition (*Cravens et al., 2005*)

New Horizons and Pluto’s Plasma Boundaries?

- ***Alice*** -- occultations (atmospheric models needed for ionospheric models and neutral densities).
- ***SWAP*** -- measures solar wind ion fluxes near Pluto. Ion flux changes should be evident near cometopause and cavity boundary (downstream). Cold ionospheric plasma seen in the wake due to ram speed?
- ***PEPSSI*** -- measures energetic particle fluxes (e.g., pickup ions) (changes near cometopause).
- ***REX*** -- radio science. Radio occultation measurements of electron density might show ionopause/cavity signatures.