Plasmasphere Modeling

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Why do we research Plasmasphere?

For TEC users,

FORMOSAT	~800 km
GPS	~20,000 km
Galileo	~23,000 km
GLONASS	~19,000 km
BeiDou	~21,000 km
NAVIC	~36,000 km
Michibiki	~42,000 km
IRI	2,000 km

Photochemistry in the Earth's Thermosphere

Photoionization

$$O + h\nu \rightarrow O^+ + e$$

$$O_2 + h\nu \rightarrow O_2^+ + e$$

$$N_2 + h\nu \rightarrow N_2^+ + e$$

Radiative recombination

$$O^+ + e \rightarrow O + h\nu$$

Dissociative recombination

$$NO^+ + e \rightarrow N + O$$

$$O_2^+ + e \rightarrow O + O$$

$$N_2^+ + e \rightarrow N + N$$

Charge exchange reactions

$$O^+ + N_2 \rightarrow NO^+ + N$$

$$O^+ + O_2 \rightarrow O_2^+ + O$$

$$O_2^+ + N_2 \rightarrow NO^+ + NO$$

$$N_2^+ + O \rightarrow NO^+ + N$$

$$N_2^+ + O_2 \rightarrow N_2 + O_2^+$$

Earth’s Ionosphere and Thermosphere

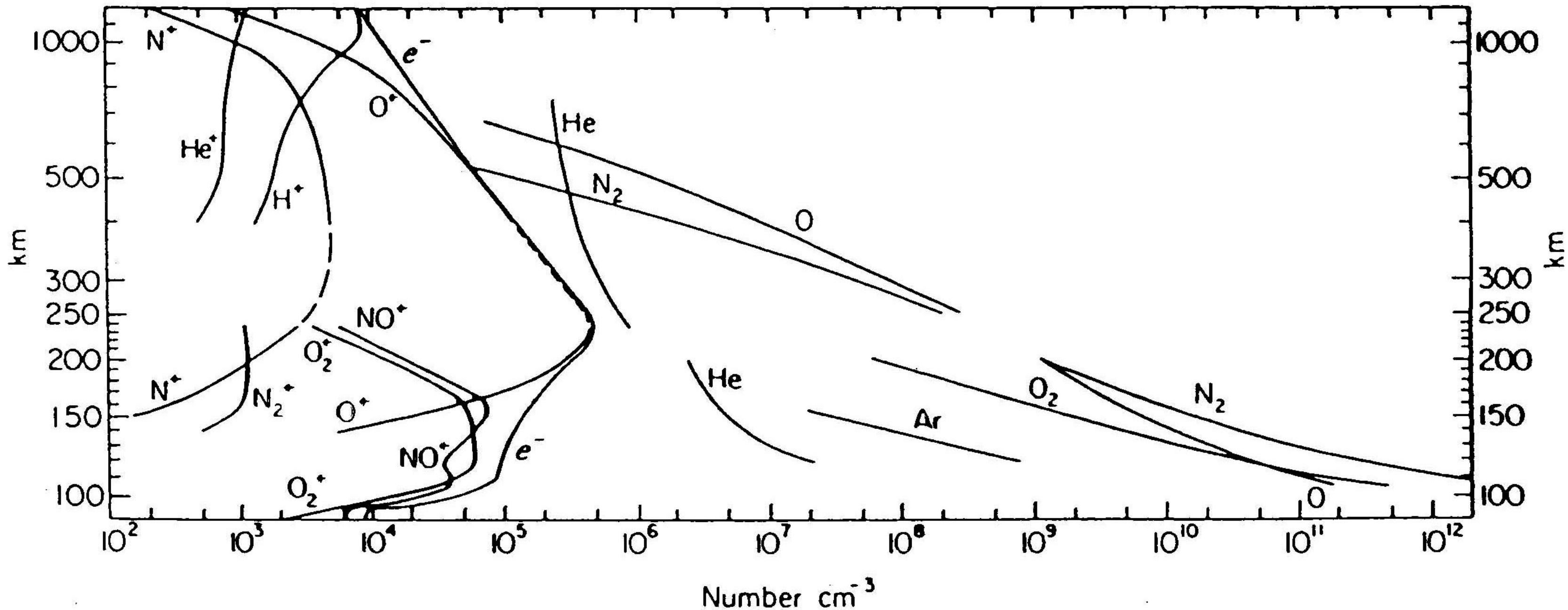


Fig. 1.2. International Quiet Solar Year (IQSY) daytime atmospheric composition, based on mass spectrometer measurements above White Sands, New Mexico (32°N, 106°W). The helium distribution is from a nighttime measurement. Distributions above 250 km are from the Elektron II satellite results of Istomin (1966) and Explorer XVII results of Reber and Nicolet (1965). [C. Y. Johnson, U.S. Naval Research Laboratory, Washington, D.C. Reprinted from Johnson (1969) by permission of the MIT Press, Cambridge, Massachusetts. Copyright 1969 by MIT.]

Photochemistry in the Earth's Upper Thermosphere (Plasmasphere)

Photoionization

$$\mathrm{H} + h\nu \rightarrow \mathrm{H}^+ + \mathrm{e}$$

$$\mathrm{He} + h\nu \rightarrow \mathrm{He}^+ + \mathrm{e}$$

Charge exchange reactions

$$\mathrm{O} + \mathrm{H}^+ \Leftrightarrow \mathrm{O}^+ + \mathrm{H}$$

Radiative recombination

$$\mathrm{H}^+ + e \rightarrow \mathrm{H} + h\nu$$

$$\mathrm{He}^+ + e \rightarrow \mathrm{He} + h\nu$$

Charge exchange reactions

$$\mathrm{He}^+ + \mathrm{N}_2 \rightarrow \mathrm{N}^+ + \mathrm{N} + \mathrm{He}$$

$$\mathrm{He}^+ + \mathrm{N}_2 \rightarrow \mathrm{N}_2^+ + \mathrm{He}$$

$$\mathrm{He}^+ + \mathrm{O}_2 \rightarrow \mathrm{O}^+ + \mathrm{O} + \mathrm{He}$$

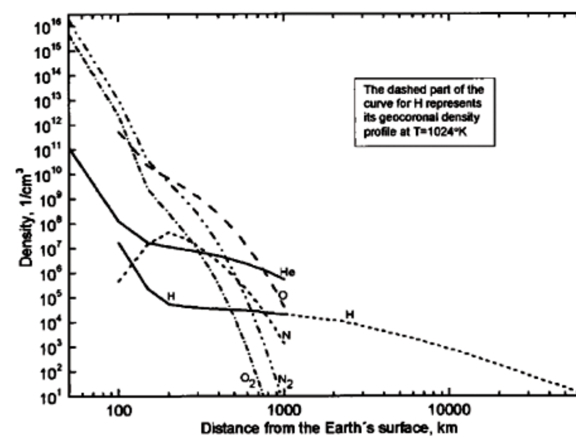
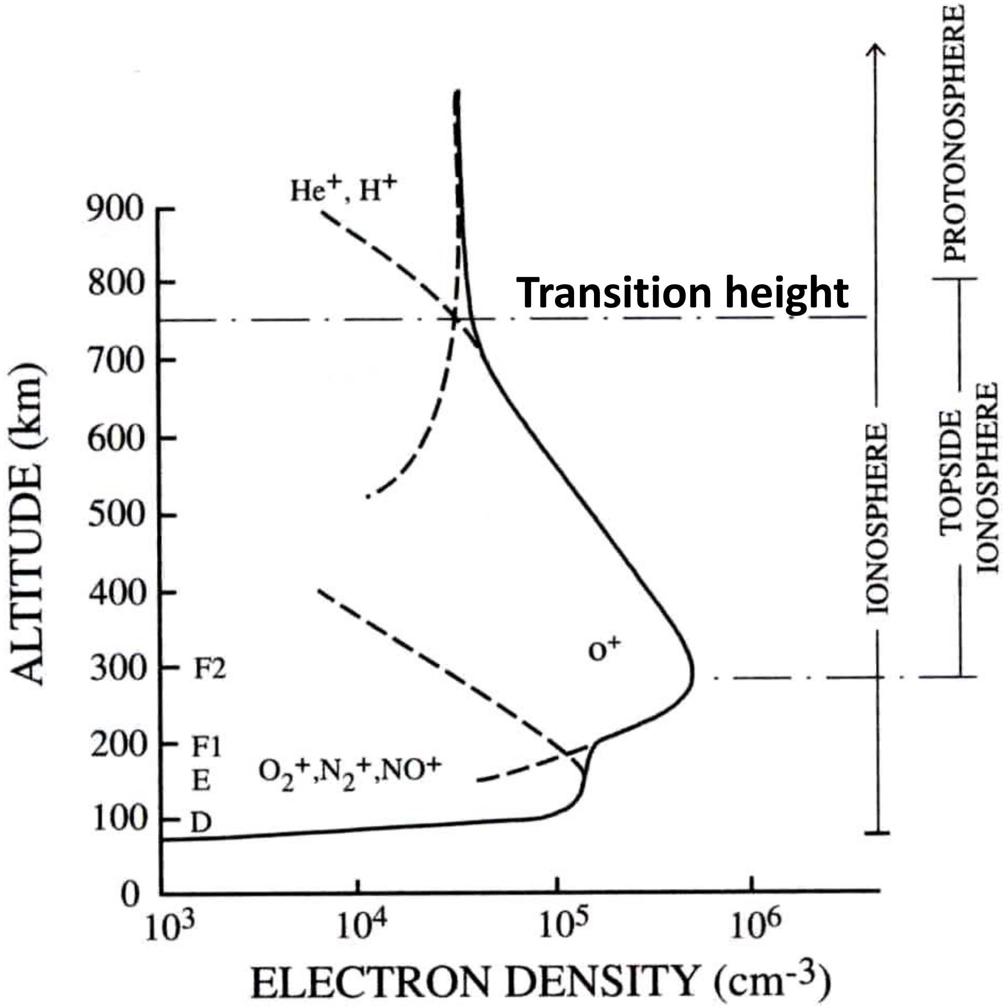


Figure 3. Atmospheric and exospheric densities according MSISE-90 model and Chamberlen geocoronal model.

Gusev et al., 2003

Earth’s Ionosphere and Plasmsphere



Plasmasphere

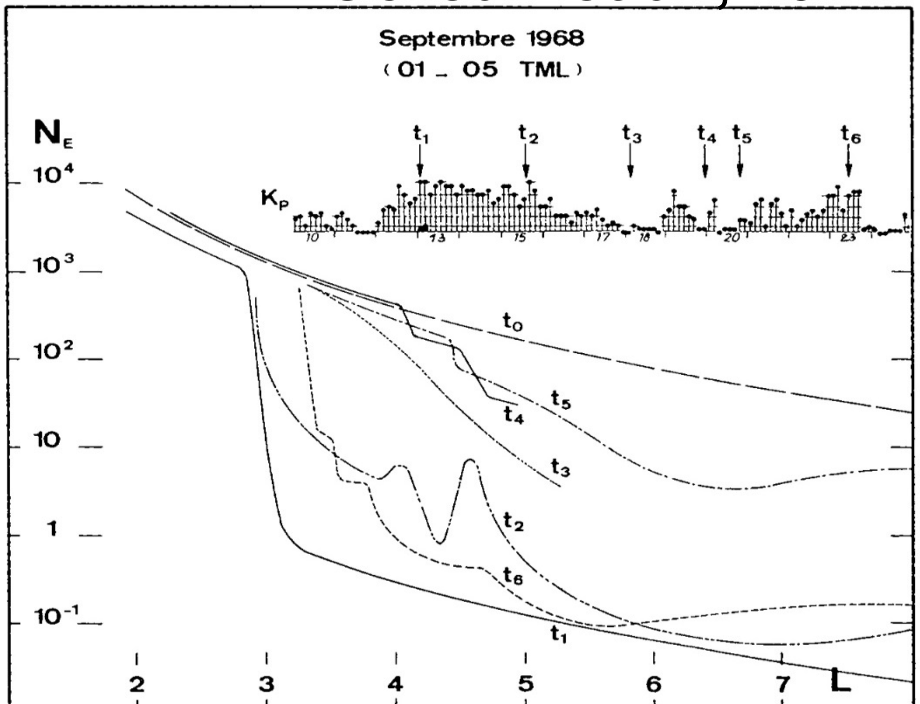
Ionosphere

Figure 2.16 Representative ion density profiles for the daytime mid-latitude ionosphere showing the layered structure (D, E, F_1, F_2 layers).[16]

Plasmapause

Corcuff et al., 1972

Ne (cm^{-3})



Plasmasphere Plasmapause

Carpenter and Park, 1973

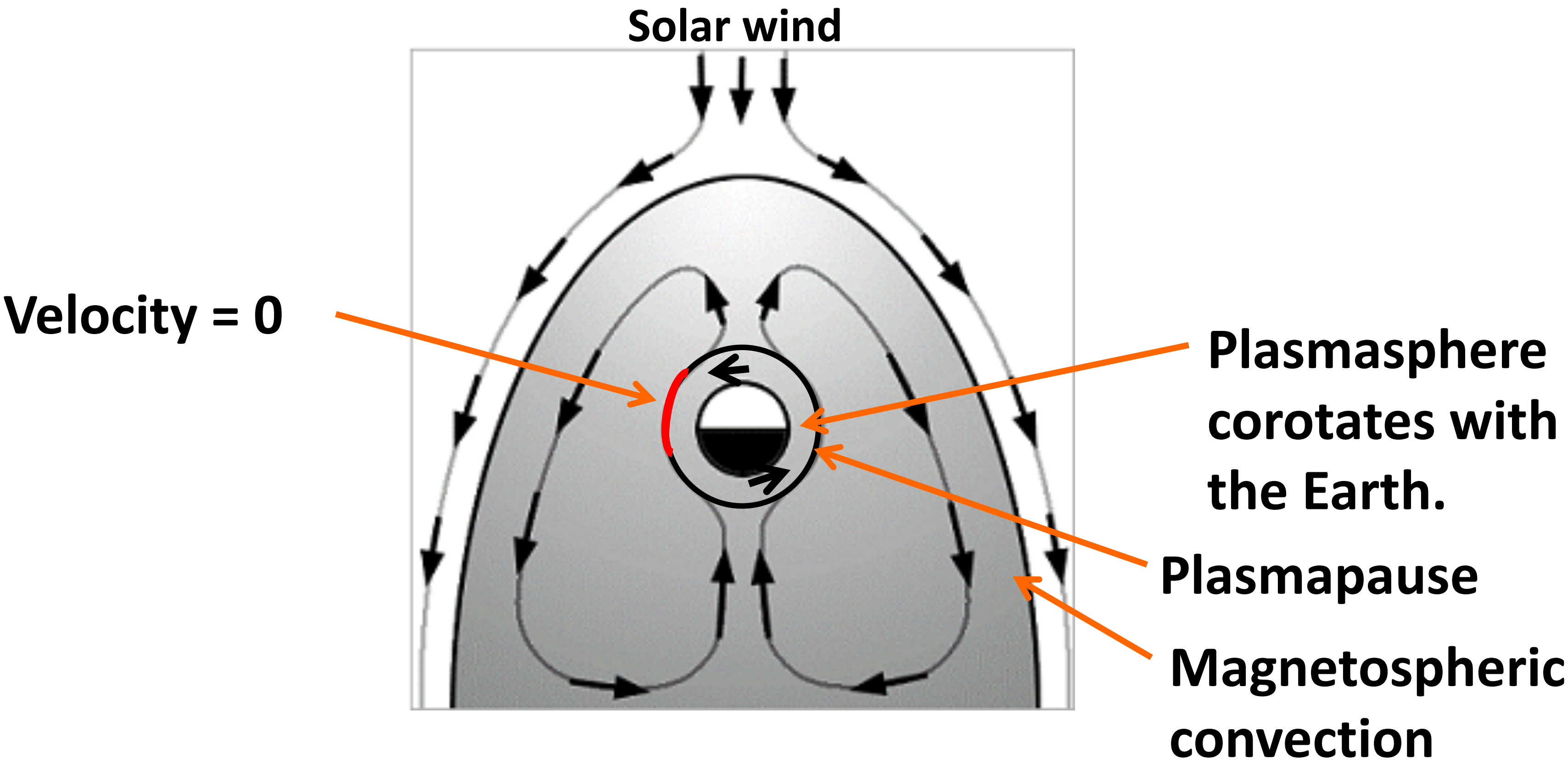
$$L_{pp} = 5.7 - 0.47 K_p$$

The location of the plasmapause depends on the magnetospheric disturbance.

Wave-like irregularity in the plasmapause results from transient, localized processes associated with substorms.

Plasma is supplied continuously from ionosphere. (Refilling)

Magnetospheric Convection



Plasmaspheric erosion (plasma tail) is the result of enhanced magnetospheric convection.

Magnetospheric Convection

$$\mathbf{E}_{conv} = -\mathbf{v}_{sw} \times \left(\mathbf{B}_{IMF} + \mathbf{B}_{pol}\right)$$

$$\mathbf{E}_{rot} = -\mathbf{v}_{cor} \times \mathbf{B}$$

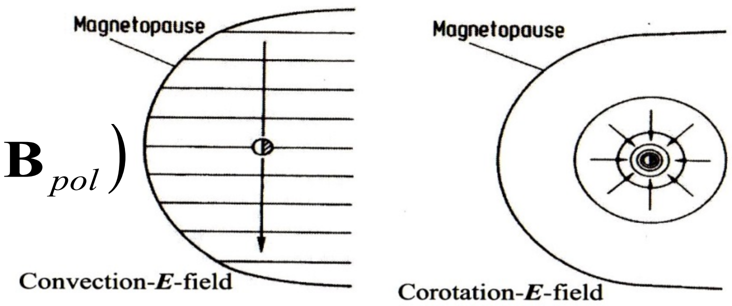


Fig. 6.1. Configuration of the convection electric field (left) induced by the solar wind plasma interaction with the magnetosphere and the corotational electric field (right) for contours in the equatorial plane (after H. O. Rucker [196]).

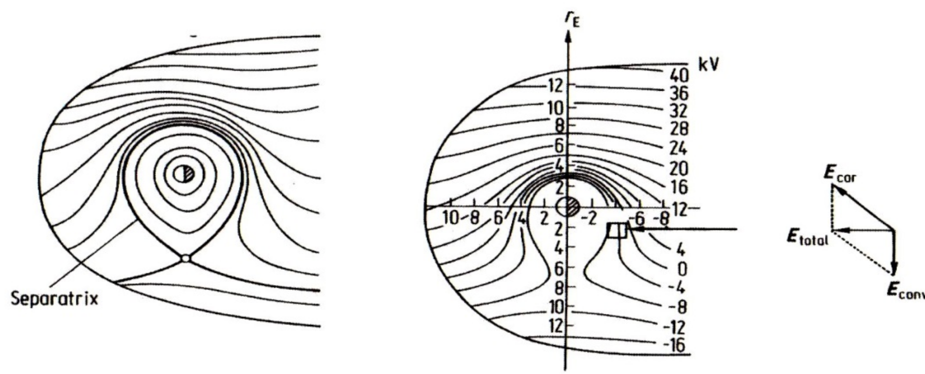
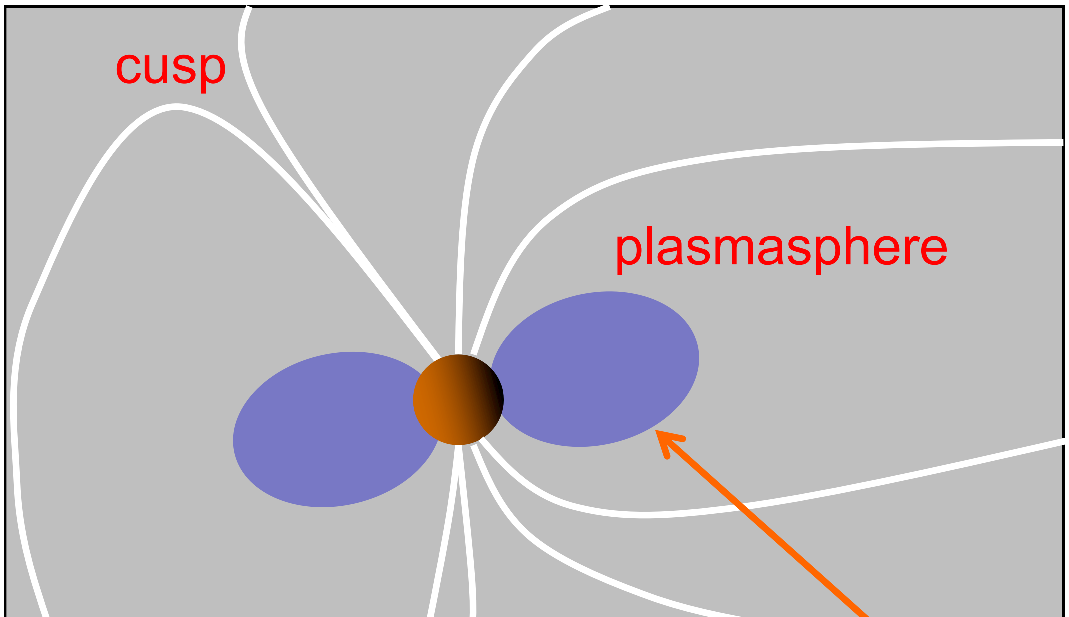


Fig. 6.2. Superposition of the convection and corotational electric fields. Theoretical illustration of the areas which are separated by a separatrix (left) and typical values for the potential difference in the terrestrial magnetosphere (after H. O. Rucker [196]).

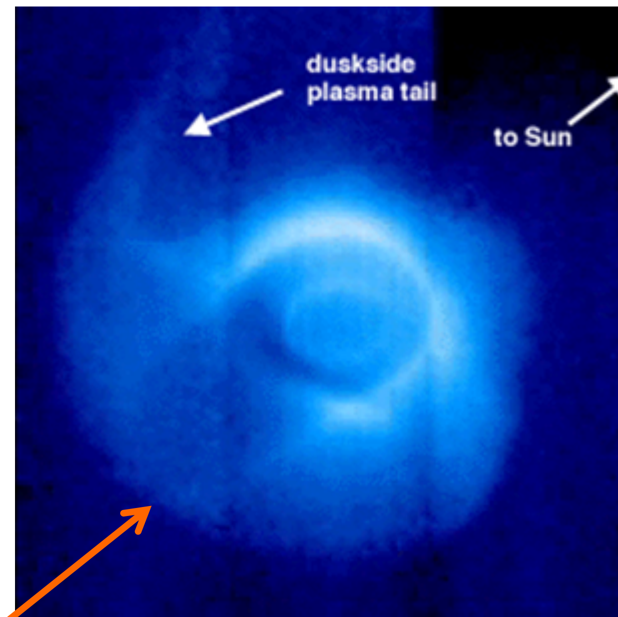
Plasmasphere and Plasma Tail

The Earth's plasmasphere is a torus of cold (~1eV) and dense (~$10^3 cm^{-3}$) plasma in the region of the inner magnetosphere. H^+ is the principal ion with ~20% He^+.

From dusk



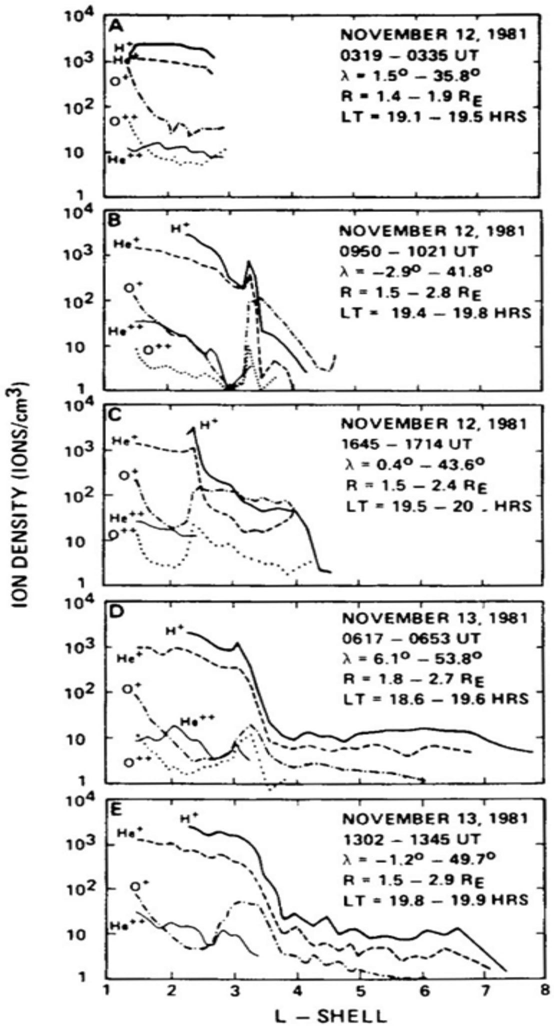
From north



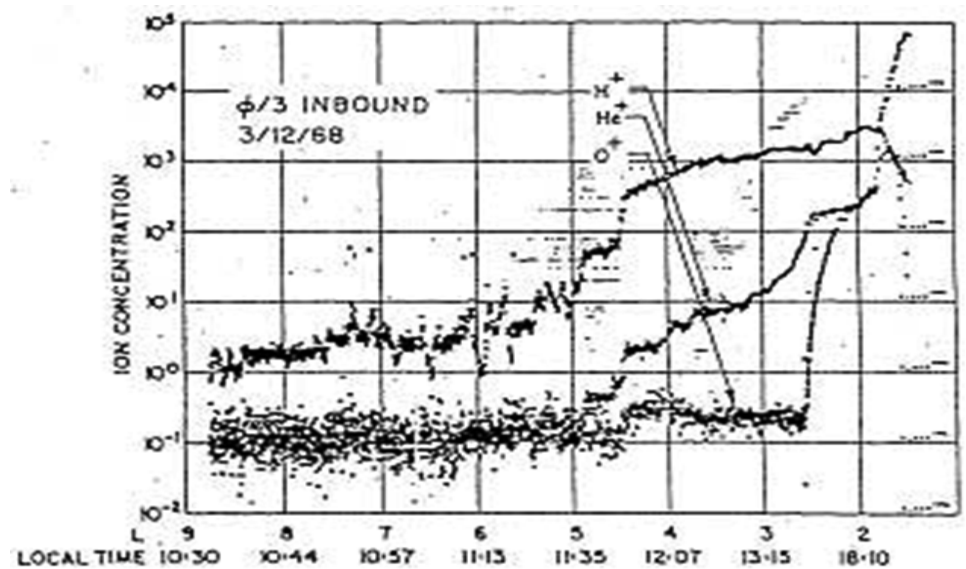
plasmapause

IMAGE He+ (30.4 nm)

Ion Composition

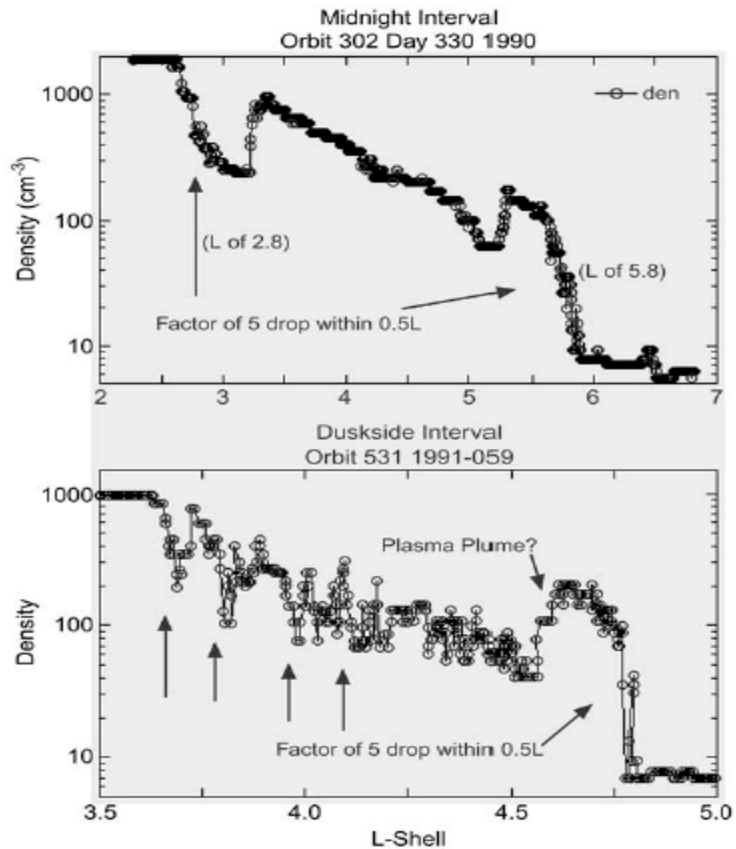


O^+ ion density reaches values comparable to the H^+ density in the region L=3-4.
(Horwitz et al., 1984)



Plasma Irregularity at Plasmapause

Plasmapause Crossings by CRRES



Moldwin et al.

Plasmapause

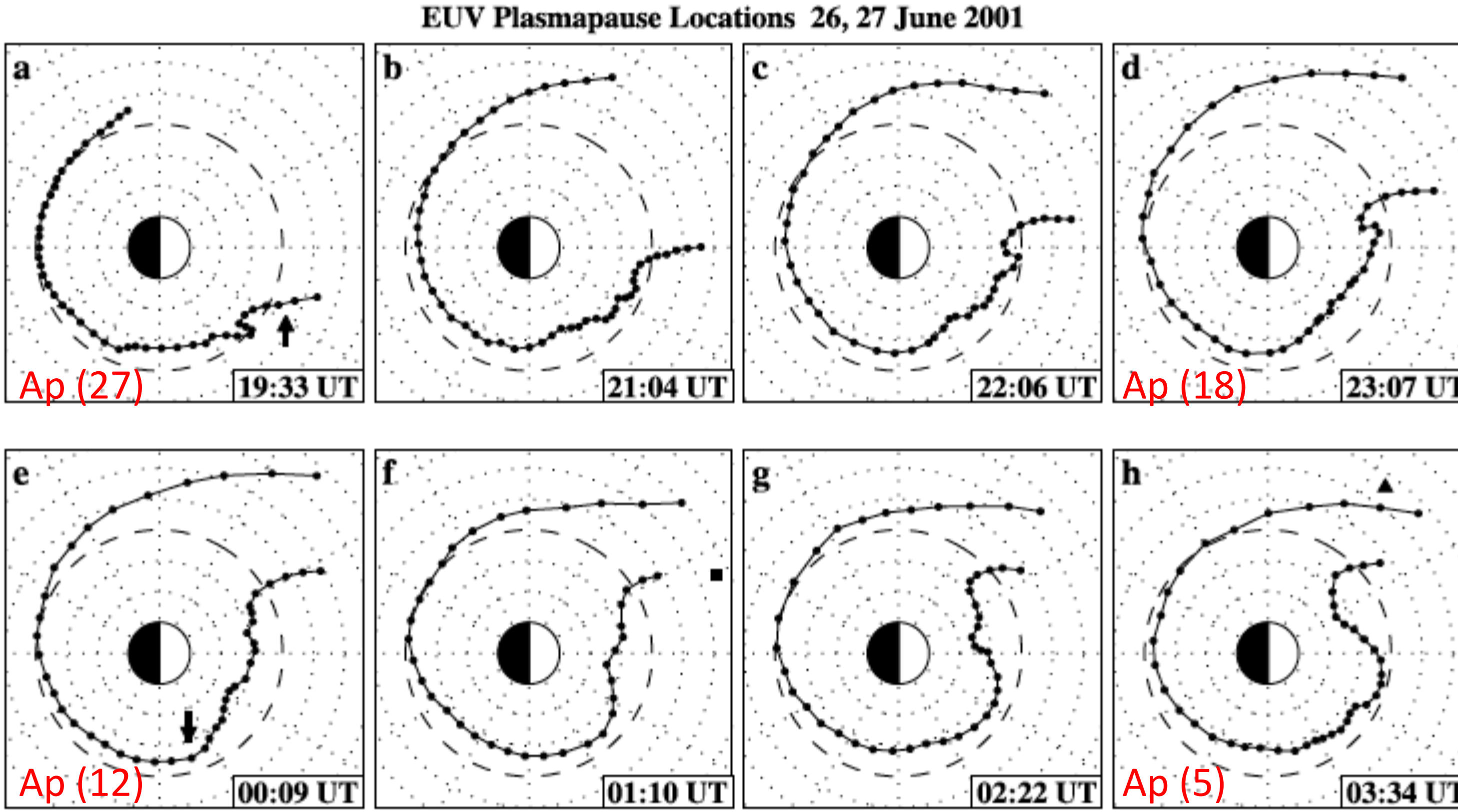
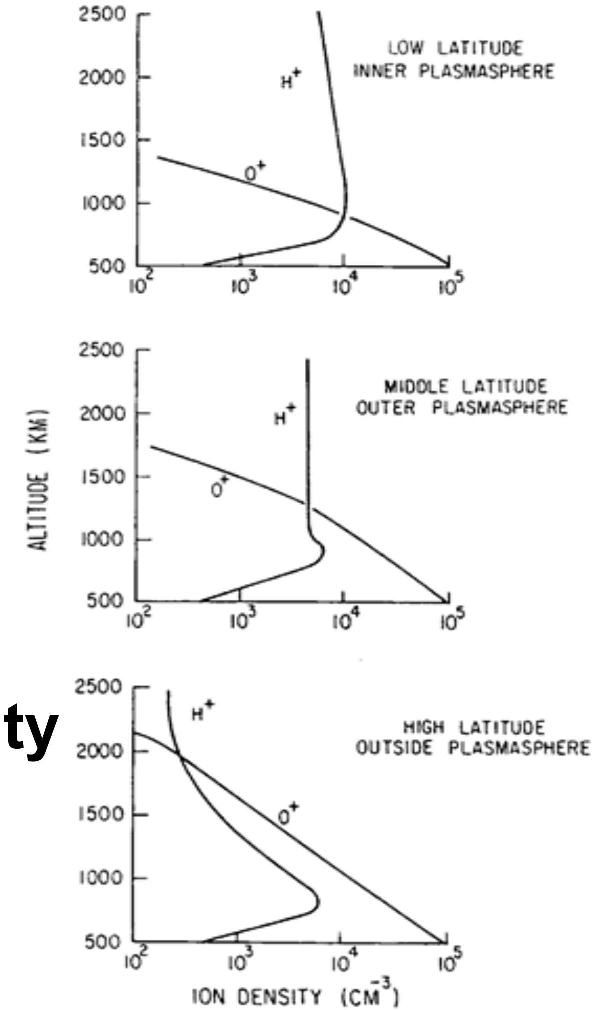


Figure 5. EUV extracted plasmapause locations from 26–27 June 2001, showing the formation of a plasmaspheric plume and a morningside shoulder. The black square in Figure 5f and the triangle in Figure 5h indicate the approximate UT and MLT times between which in situ density observations of the plume were available (Figure 7).

Spasojevie et al., 2003

Topside Ionosphere



Low latitude

Middle latitude

Why is low H+ density at high latitudes?

High latitude (outside plasmasphere)

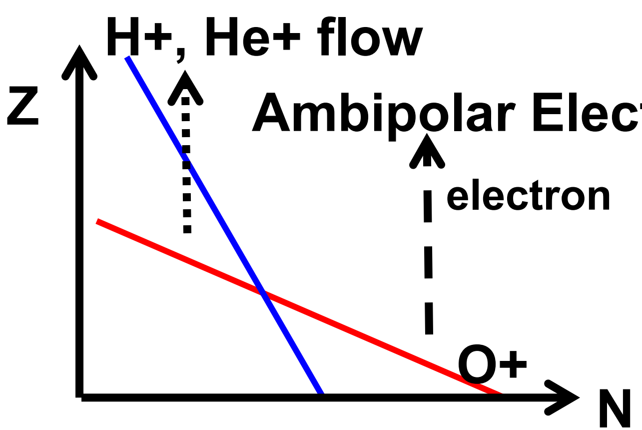
Banks et al., 1976

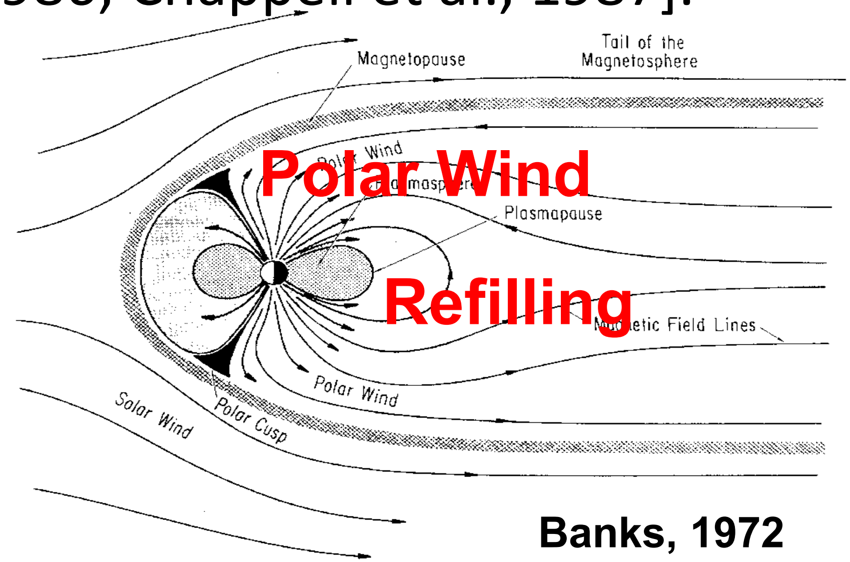
Polar Wind

Axford [1968] pointed out that the <u>lighter ions</u> must escape from the earth by the flux of escaping photo-electrons with energies greater than 2.4 eV, and suggested the ion escape speed of ~10 km/sec.

This phenomenon is called 'Polar Wind'.

The polar wind is important as a source of magnetospheric plasma [Shelley et al., 1982; Moore et al., 1986; Chappell et al., 1987].





Banks, 1972

Thermal Ion Outflow

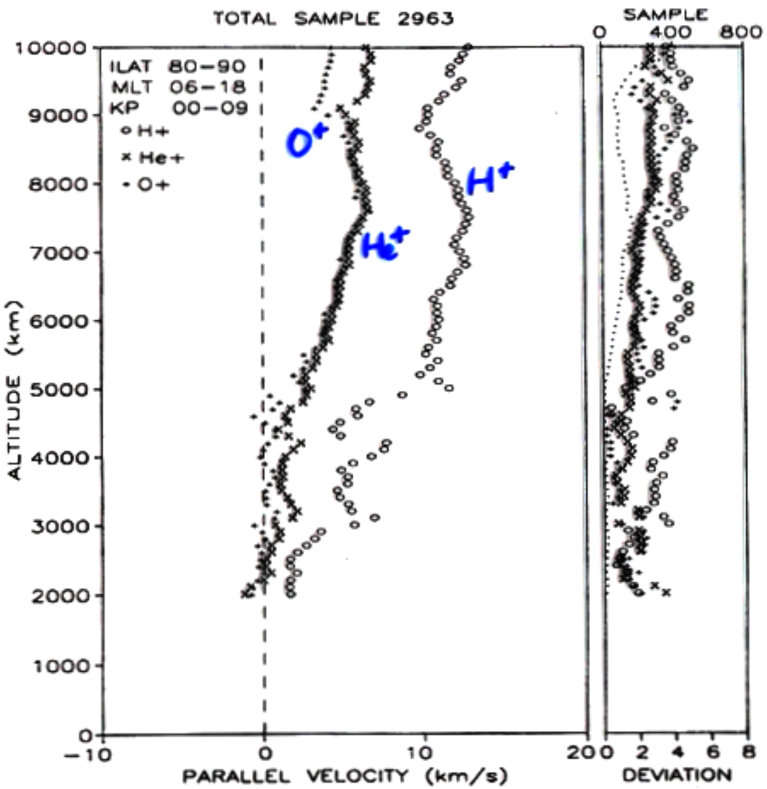


Fig. 4. Parallel ion velocity of the polar wind in the dayside (06-18 MLT) as a function of altitude, averaged over all *Kp* levels and all invariant latitudes above 80°. See Figure 3 caption for explanation.

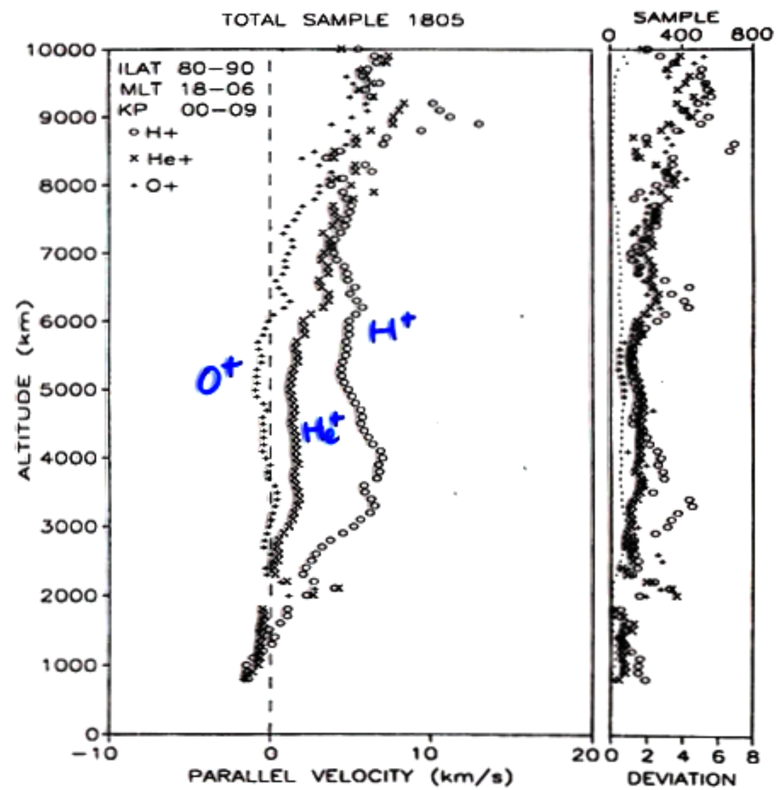


Fig. 5. Parallel ion velocity of the polar wind in the nightside (18-06 MLT) as a function of altitude, averaged over all *Kp* levels and all invariant latitudes above 80°. See Figure 3 caption for explanation.

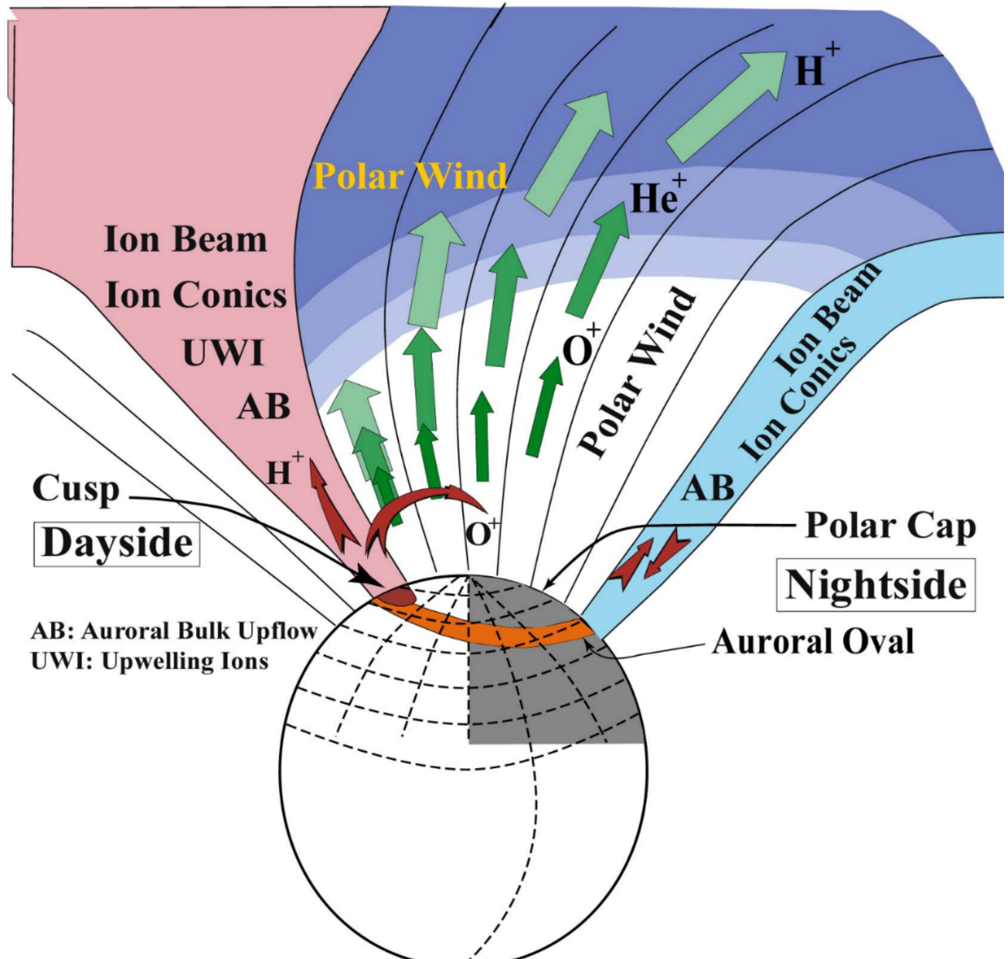
Akebono/SMS

Abe et al., 1993

Near magnetic pole,

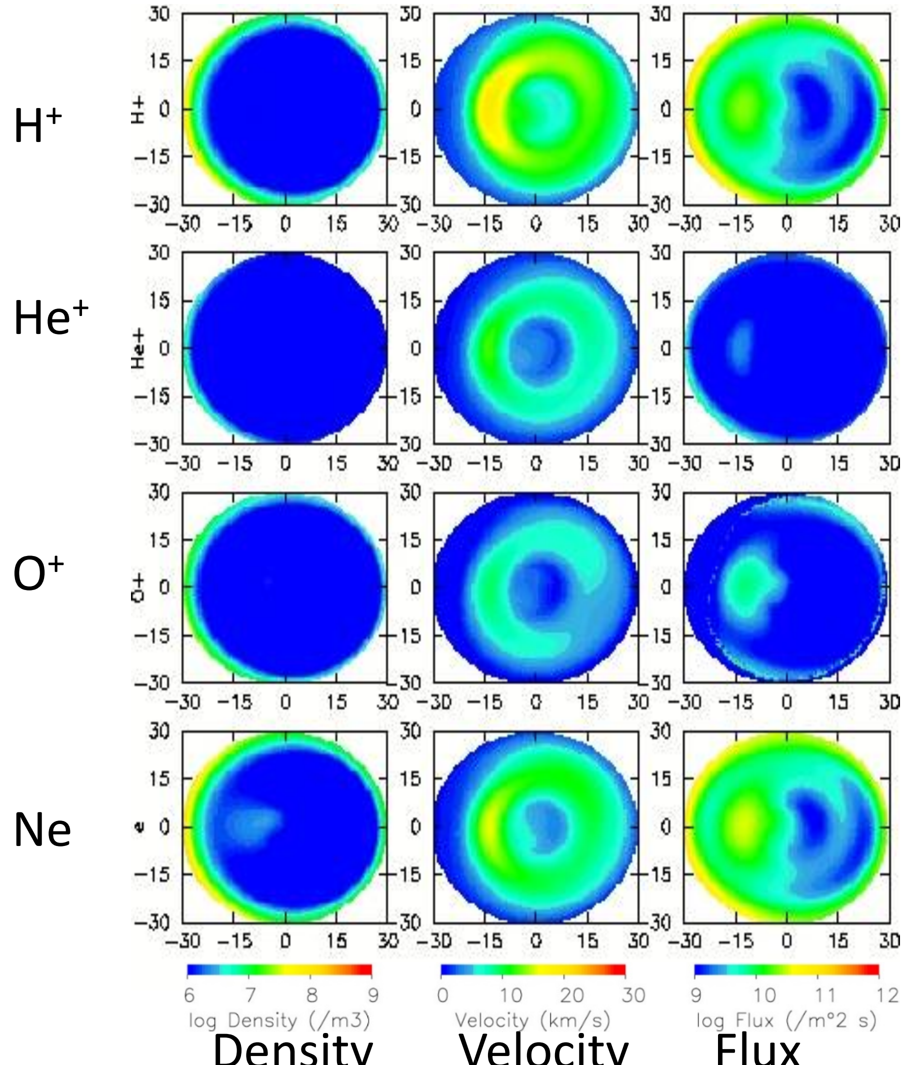
all ionospheric ions are flowing to Magnetosphere.

Ion Outflow from Topside Ionosphere

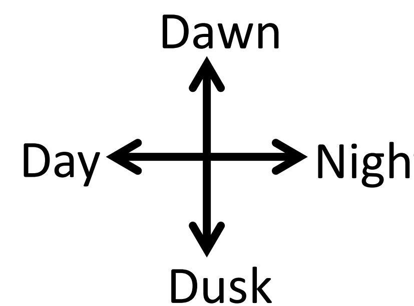


Abe

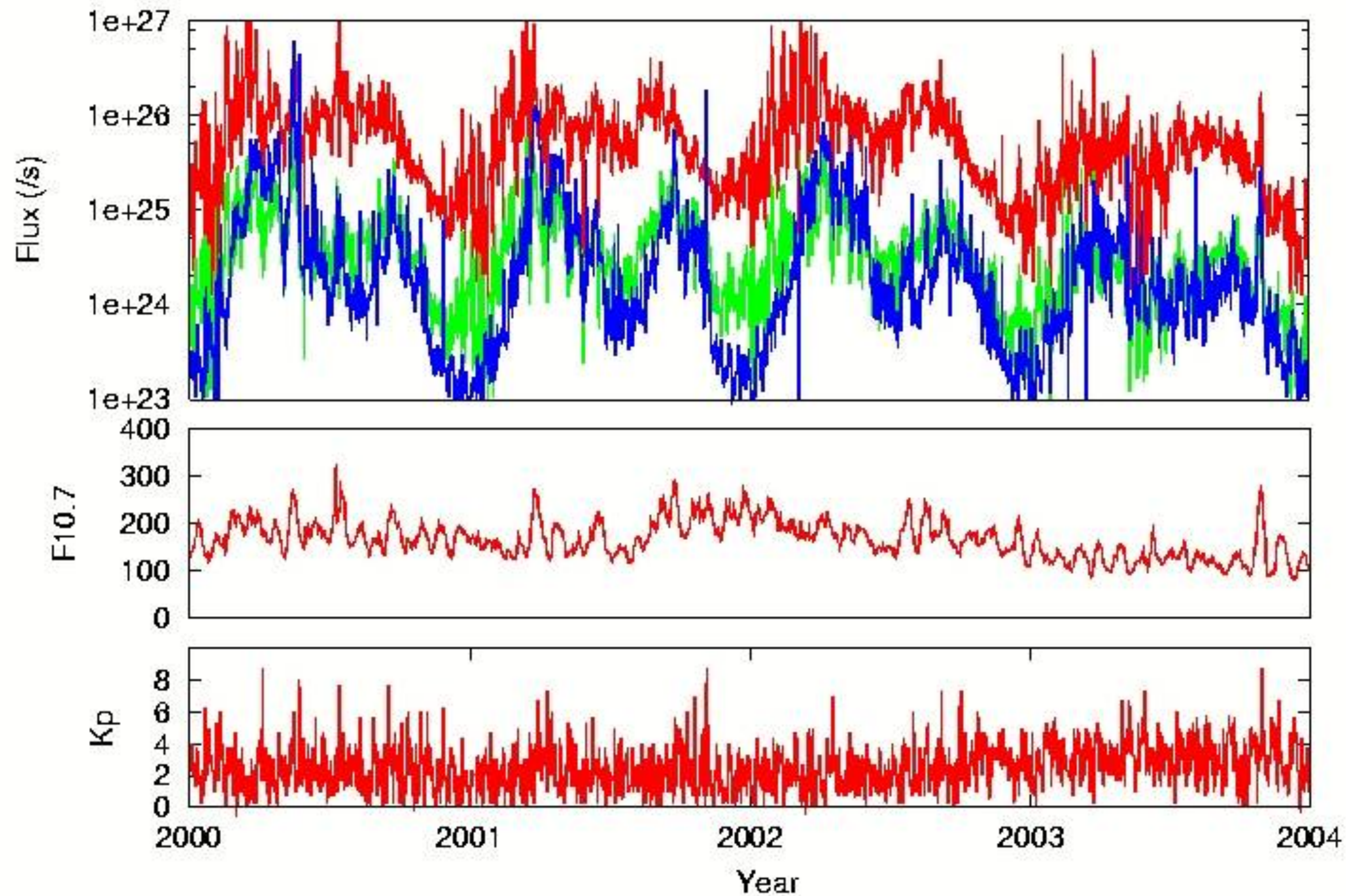
Ion Outflow Model from Akebono/SMS



2003/1/25
Kp: 3
$F_{10.7}$: 125
Altitude: 6000km
Northern hemisphere



Escape Flux at 6000 km altitude in the northern hemisphere
Suprathermal Ion Mass Spectrometer (SMS)



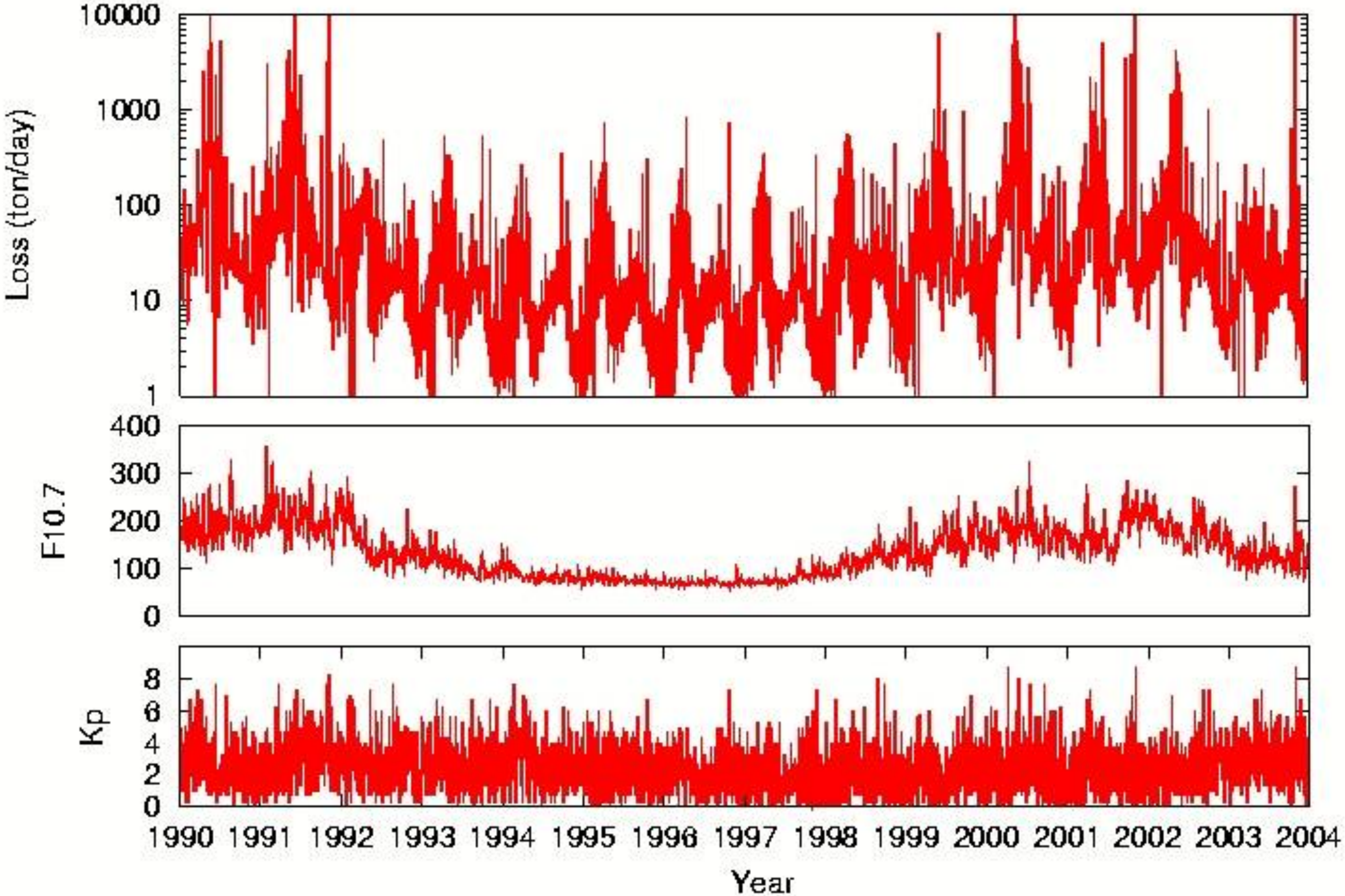
H+

He+

O+

Watanabe, 2011

Ion Loss from polar ionosphere
Suprathermal Ion Mass Spectrometer (SMS)



Watanabe, 2011

- Global Core Plasma Models

(D.L. Gallagher, P.D. Craven, and R.H. Comfort)
Plasmasphere, plasmapause, magnetospheric trough, and IRI model for ionospheric densities
Seasonal and solar cycle variations

- Plasmasphere Models (Akebono Model)

(Kutiev, I., K.-I. Oyama, S. Watanabe, T. Abe, and A. Kumamoto)
Plasmasphere electron temperature

- IMAGE Model [info]

(Huang, X., B.W. Reinisch, P. Song, P. Nsumei, J.L. Green, D.L. Gallagher)
Empirical Models of the Plasma Density

- IZMIRAN10

(Chasovitin and Gulyaeva)
From whistlers and satellites data
Electron density smoothly fitted to IRI electron density profile at 1000 - 36,0000 km altitude.
Solar activity and magnetic activity

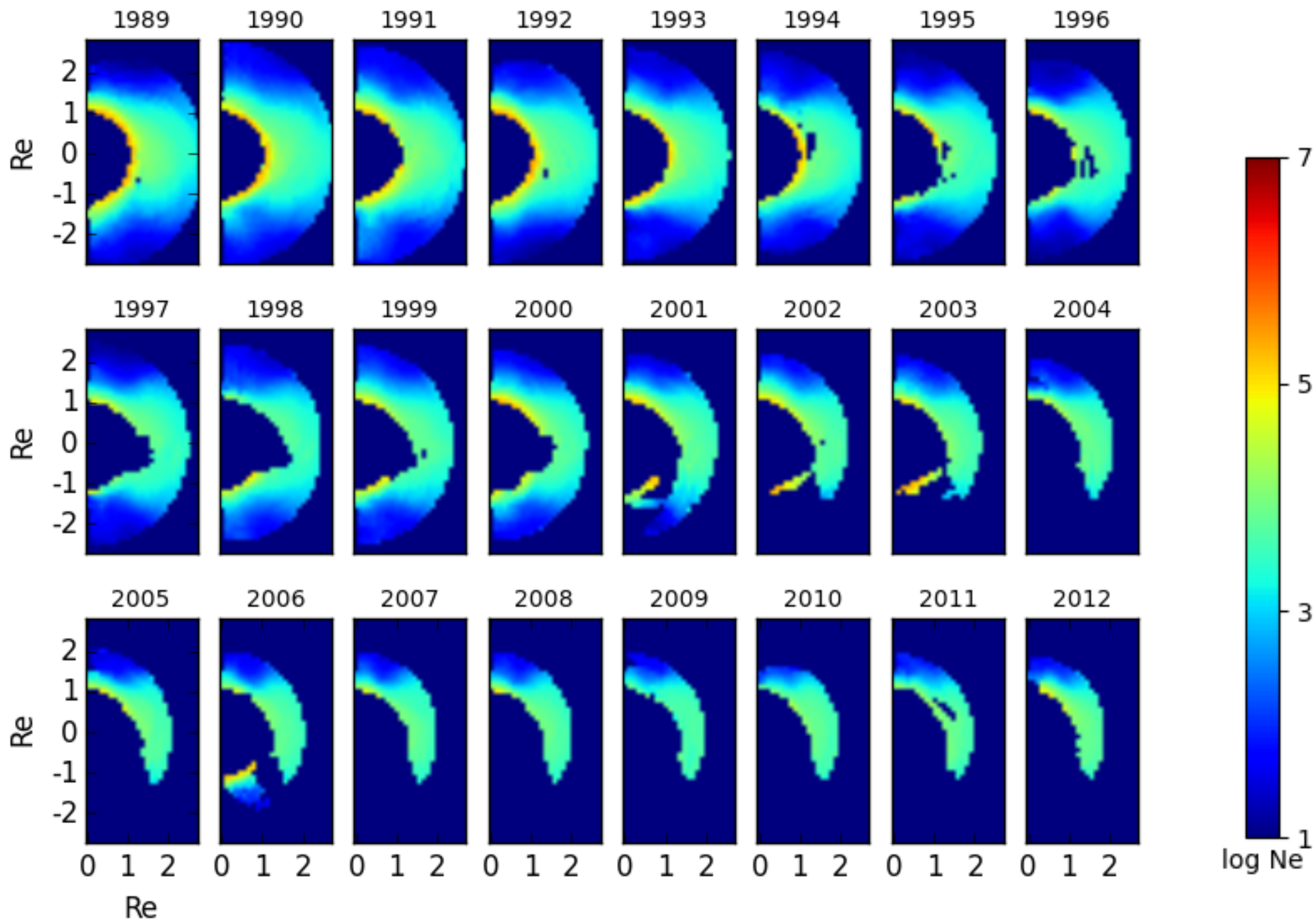
- O'Brian and Moldwin

(CRRES observations)
Empirical models of the plasmapause location as a function of Kp, AE, and Dst

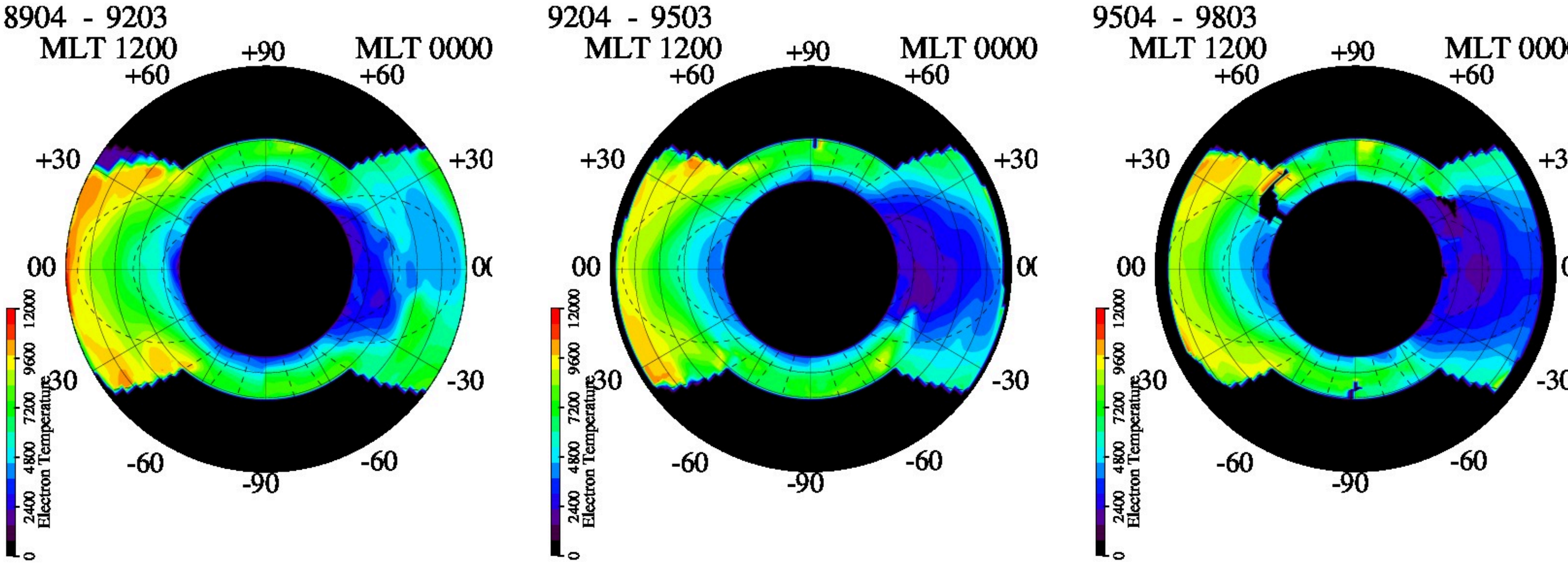
- European Space Weather

Plasmasphere models for density (V. Pierrard & K. Borremans, BISA), density and temperature (V. Pierrard & K. Borremans), and the plasmapause (V. Pierrard)

Electron Density observed by PWS on Akebono Satellite

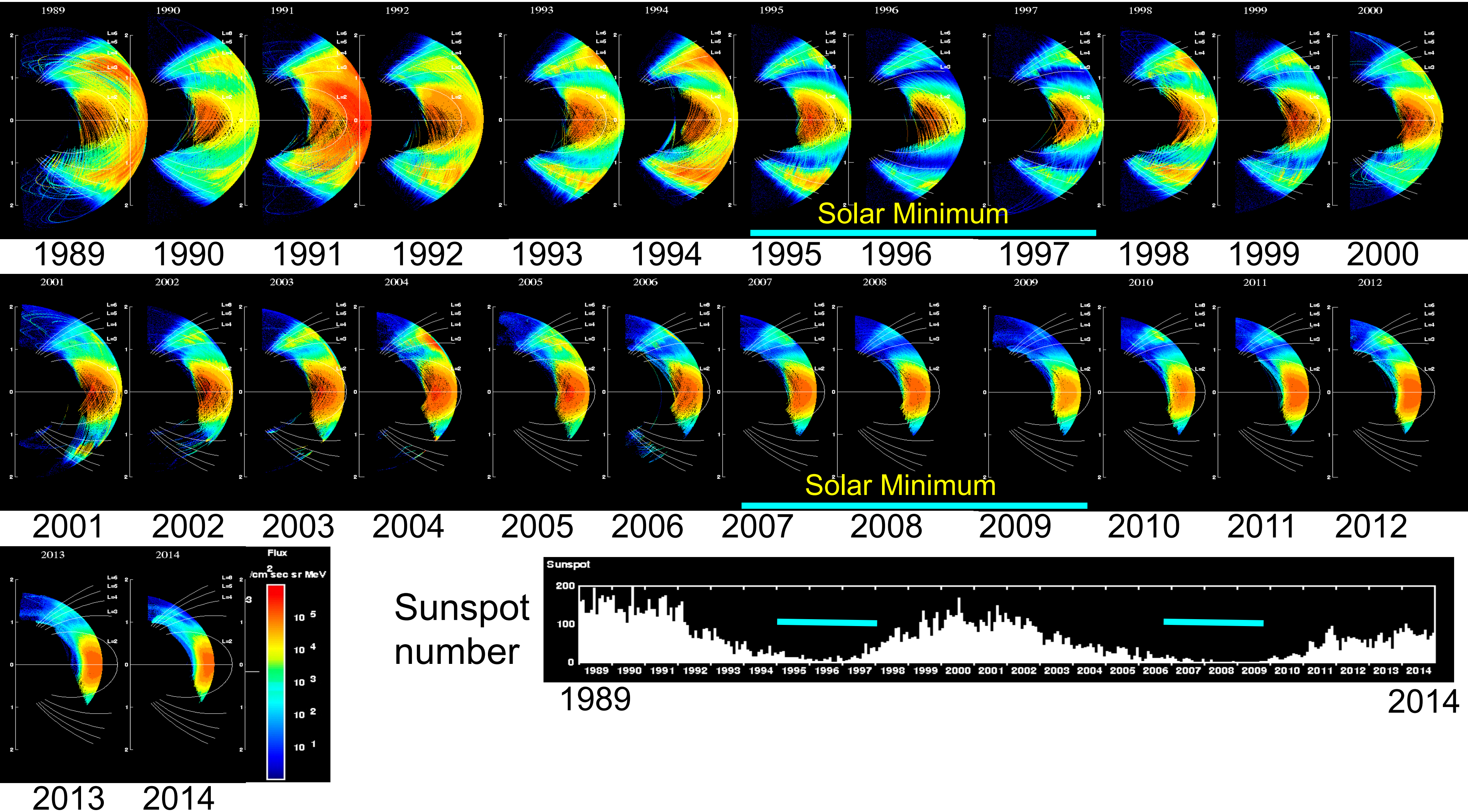


4,412,579 Electron Density Data Sets

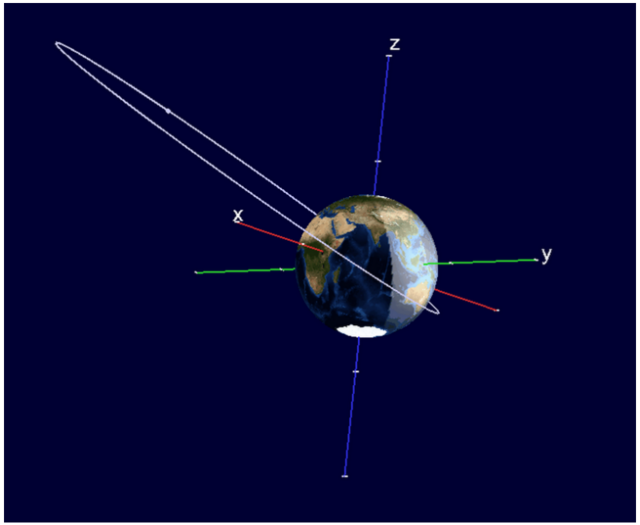

8904 - 9203
MLT 1200
MLT 0000
+90
+60
+30
00
-30
-60
-90
Electron Temperature
0
2400
4800
7200
9600
12000
9204 - 9503
MLT 1200
MLT 0000
9504 - 9803
MLT 1200
MLT 0000

Abe, 2015

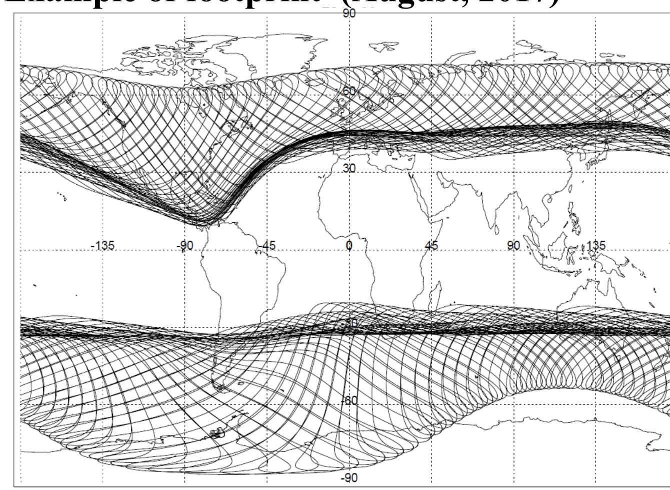
Akebono Radiation Monitor (RDM) > 2.5MeV electron flux



Arase Orbit



Example of footprint (August, 2017)

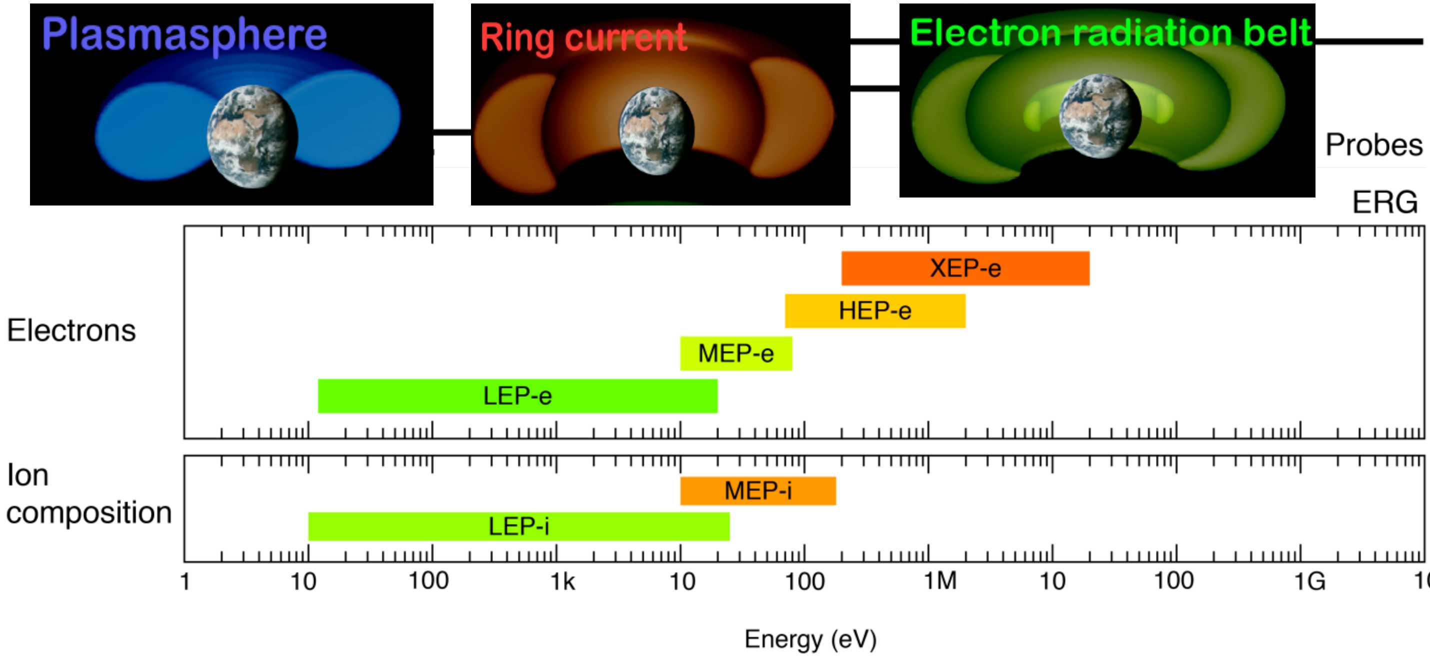


- Launch: December 20, 2016
- Start of observations: end of March, 2017
- Apogee : 32246 km (~6Re)
- Perigee : > 400 km
- Inclination : 31 deg
- Spin Period : 8sec
- Orbital Period 563 min

Contact: Project Manager Iku Shinohara (ISAS/JAXA): iku@stp.isas.jaxa.jp
Project Scientist Yoshi Miyoshi (Nagoya U): miyoshi@isee.nagoya-u.ac.jp

Plasma & particles

Electron 17eV-20MeV, Ions 10eV/q-200keV/q



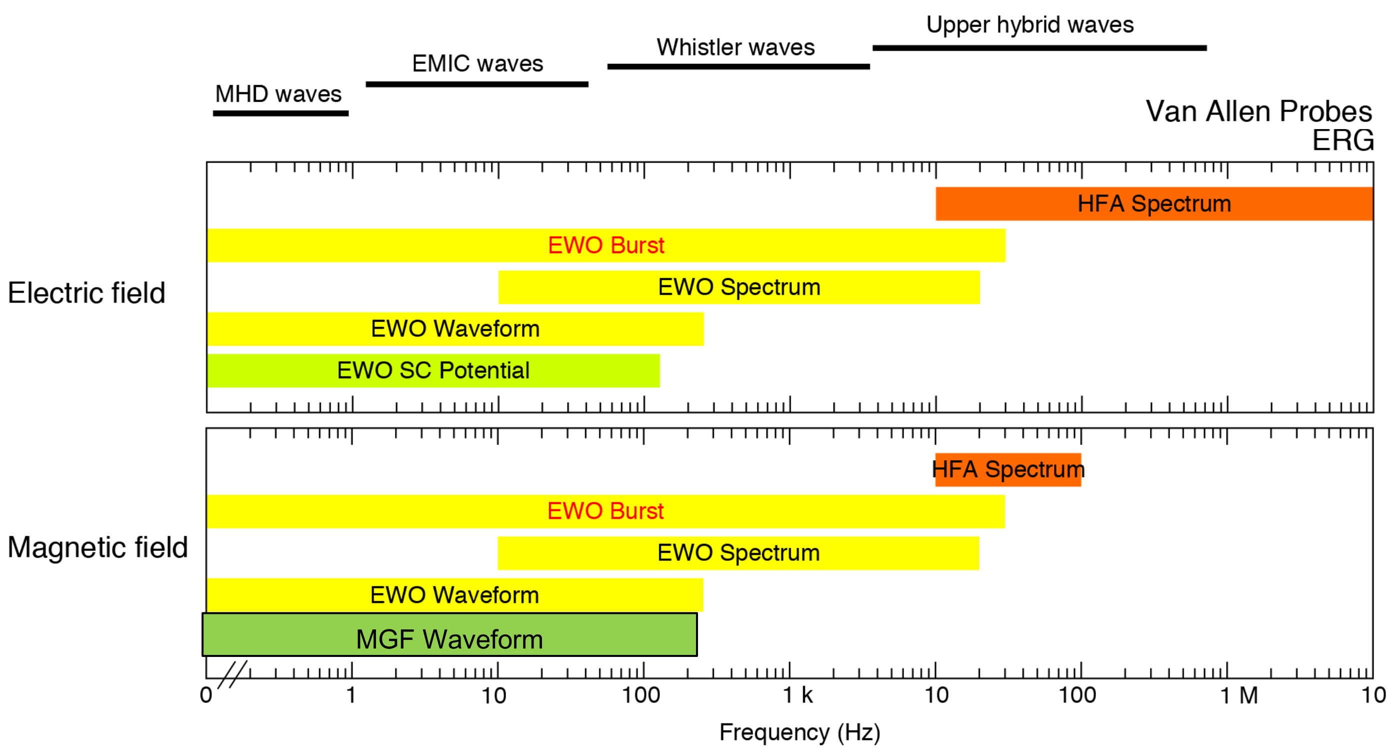





Field and Waves

PWE: Plasma Wave and Electric Field Experiment
(E: DC-10MHz)
(B: ULF- 100 kHz)

MGF: Magnetic Field measurement (B: DC-256 Hz)



Quick Look plots are found at ERG-Science Center.

Questions

- What is the detailed generation and loss processes of plasmasphere?
- What is the energetics of plasmasphere?
- What is the structure of plasmapause and the generation of plasma density irregularity at plasmapause?
- What is the coupling process between plasmasphere and geocorona?
- What is the coupling process between plasmasphere and magnetospheric plasma?
- What is the coupling process between plasmasphere and radiation belt?
- What is the loss rate of the Earth’s plasma and the atmosphere?
- Does the plasma loss contribute the evolution of the Earth’s atmosphere?