3D modeling of the density distribution in the plasmasphere using the Interball-1 data base.

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The data of the Alpha-3/INTERBALL-1 (1995-2000) are collected into a data base including:

coordinates of the satellite,

density of protons,

temperature of protons,

SC potential,

solar activity indices,

solar wind parameters.

The SC crossed the plasmasphere once per 4 days (when the perigee was low enough).
Ion spectra were measured during 2 s. Frequency of spectra measurements changed from ~18 s to ~2 min. depending on telemetry mode.

The data base contains ~10 000 spectra.

Field aligned density distribution of protons as a function of geomagnetic latitude: J.F. Lemaire et al.

For modeling plasma density distribution on a fixed *L* – shell *N(L,λ)* depending on geomagnetic latitude *λ* the following expression was used:

$$N(L,\lambda) = N_0(L) e^{-q(L,\lambda)} \left\{ 1 - (\mathbf{1} - \boldsymbol{\alpha}) \sqrt{1 - \eta(L,\lambda)}\, e^{-\frac{\eta(L,\lambda) q(L,\lambda)}{1-\eta(L,\lambda)}} \right\}$$

$$q(L,\lambda) = \frac{m_p g_e R_e}{2kT_p L} \left[\frac{1}{cos^2\lambda_0} - \frac{1}{cos^2\lambda} + \frac{1}{3}\left(\frac{L}{L_R}\right)^3 (cos^6\lambda_0 - cos^6\lambda) \right]$$

L_R = 5.78 – Roshe limit, $N_0(L)$ – proton density at exobase,

λ_0=acos$\sqrt{\frac{R_e+h_{ex}}{LR_e}}$, h_{ex} – exobase height, $\eta(L,\lambda)=\frac{B(L,\lambda)}{B(L,\lambda_0)}=\sqrt{\frac{4-3cos^2\lambda}{4-3cos^2\lambda_0}}\frac{cos^6\lambda_0}{cos^6\lambda}$

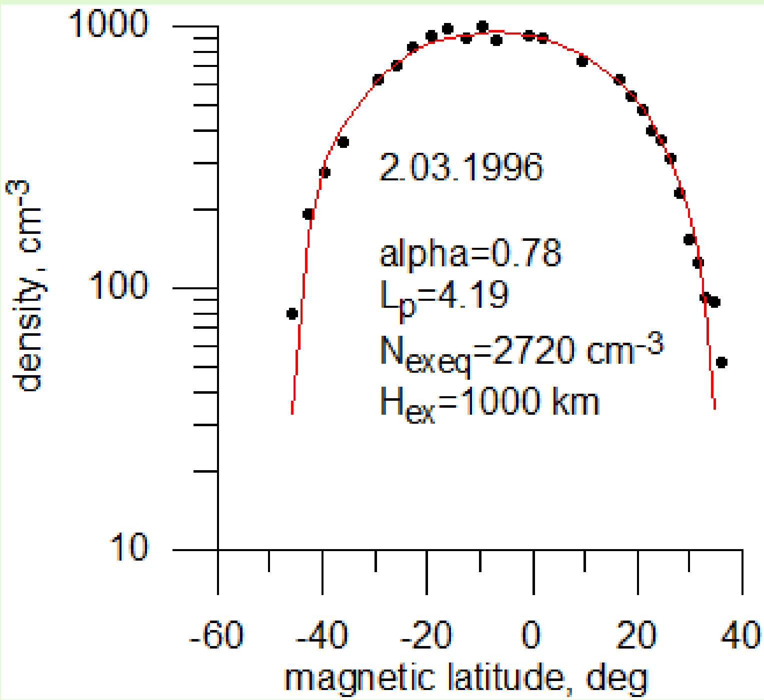
Instead of $N_0(L)= N_0(L,\lambda_0)$, equatorial density was used:

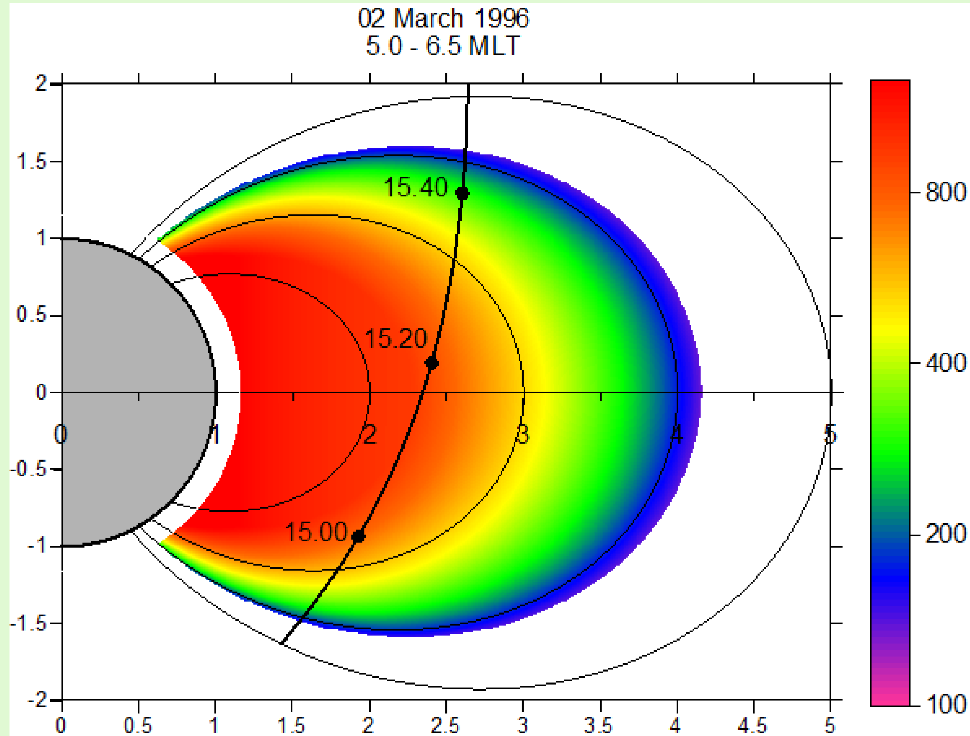
$N_{eq}(L)= N(L,0)= A\left(\frac{1}{L}-\frac{1}{B}\right)$ (Huang et al., 2004)

Parameter ***A*** can be expressed via plasma density at exobase on the equator N_{ex}
Parameter ***B*** is a function of plasmapause position, e.g., defined as L-shell where the number density dropped by a factor of 5 or more within $\Delta L \leq 0.5$ (Carpenter & Anderson, 1992).

3 parameters for approximation: $\boldsymbol{N_{ex}}$, ***B***, α

Reconstruction of proton density distribution in the meridional plane using the data of one plasmasphere crossing by INTERBALL 1.

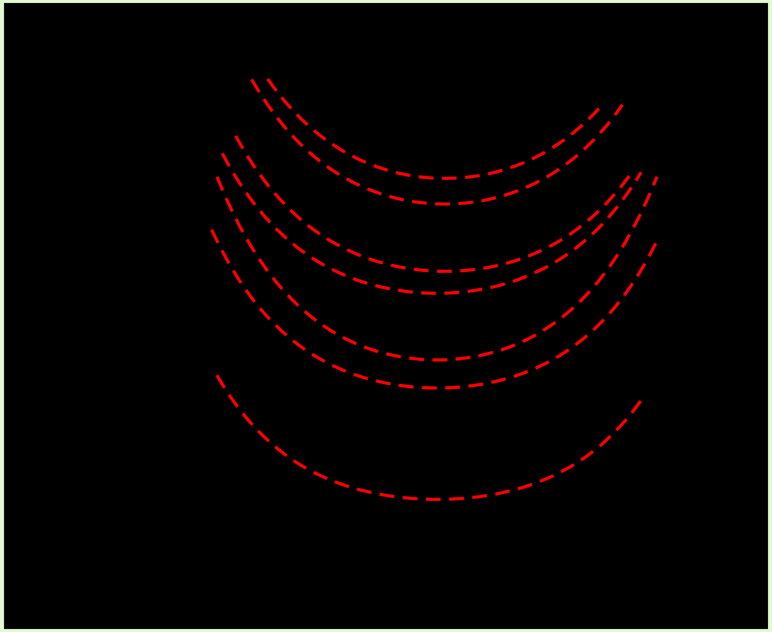




M.I. Verigin et al., *Geomagnetism and Aeronomy,* ***52****(6), 725–729, 2012.*

The 2D model was tested with IMAGE data

The proposed model based on physical equations of plasmasphere filling (Lemaire & Scherer, Sp.Sci.Rev., 591, 1974) with 4 free parameters α, L_p, N_{eq}, $\Delta\lambda$ well describes the data of IMAGE too.



The original model proposed by Reinisch et al. (Sp.Sci.Rew., 231, 2009):

$$N_e(L,\lambda) = N_{e0}(L)(1+\gamma\frac{\lambda}{\lambda_{inv}})\sec^{\beta(L)}(\frac{\pi}{2}\frac{\alpha\lambda}{\lambda_{inv}})$$

$$N_{e0}(L) = A(B/L-1)$$

$$\beta(L) = C + D\cdot L$$

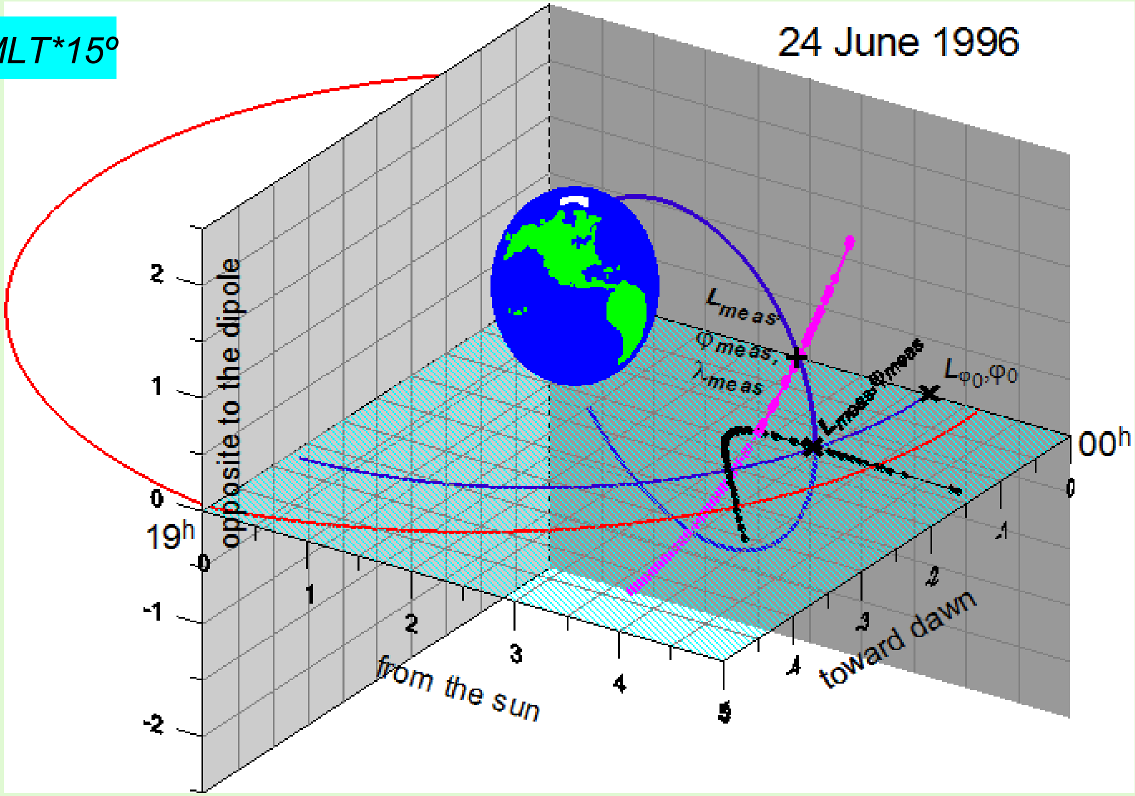
includes **6 fitting parameters: *A, B, C, D, γ, α***

3D modeling of plasma distribution inside the plasmasphere

In the equatorial plane:

$$\Phi_{conv}(L,\varphi) = E_0 R_E L^a \sin(\varphi - \varphi_0), \quad \varphi = MLT*15^o$$

$$\Phi_{corr}(L,\varphi) = -\frac{\omega_E B_0 R_E^{\ 2}}{L}$$



Flow lines: $\Phi = \Phi_{corr} + \Phi_{conv} = \Phi_c$

$$E_0 R_E L^a \sin(\varphi - \varphi_0) - \frac{\omega_E B_0 R_E^{\ 2}}{L} = \Phi_c$$

'Stagnation' point: $\frac{\partial \Phi}{\partial L} = 0, \ \varphi - \varphi_0 = -\frac{\pi}{2}$

$$L_S^{a+1} = \frac{\omega_E B_0 R_E}{a E_0}$$

$$L^a \sin(\varphi - \varphi_0) - a\frac{L_S^{a+1}}{L} = -a\frac{L_S^{a+1}}{L_{\varphi_0}}$$

Plasmapause (passing through L_S):

$$\left(\frac{L}{L_S}\right)^{a+1} \sin(\varphi - \varphi_0) + (a+1)\frac{L}{L_S} - a = 0$$

At the point of measurement:

$$N_{mod}(L_{meas}, \varphi_{meas}, \lambda_{meas}) = N_{eq} e^{-q(L,\lambda)} \left\{ 1 - (1-\alpha)\sqrt{1 - \eta(L,\lambda)} e^{-\frac{\eta(L,\lambda) e^{-q(L,\lambda)}}{1 - \eta(L,\lambda)}} \right\}$$

Model density distribution in the equatorial plane

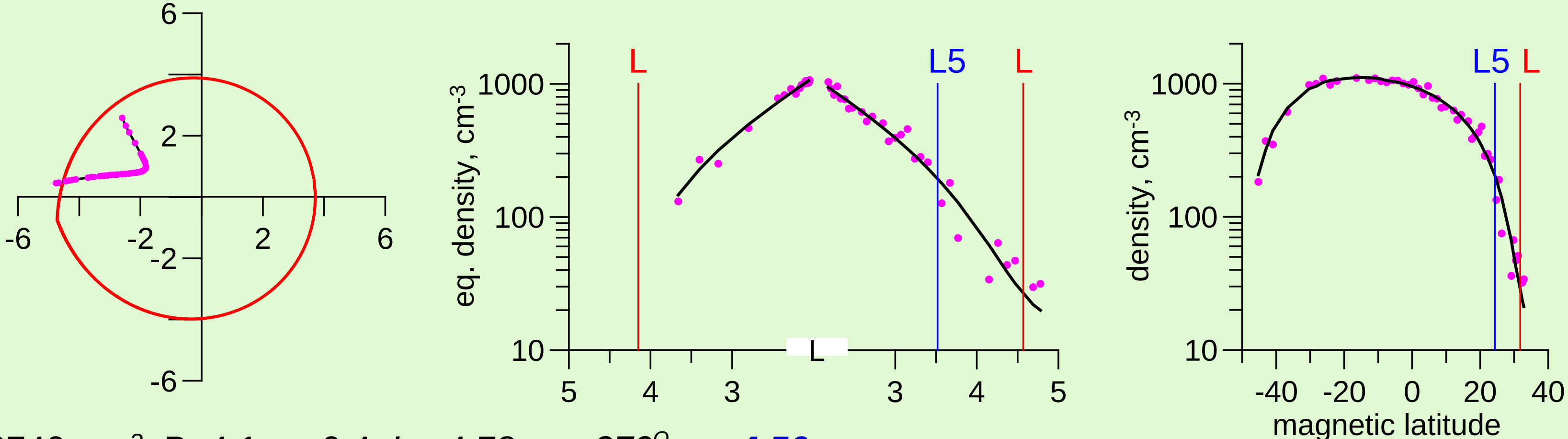
for $\varphi = \varphi_0$ $\qquad N_{eq0}(L_{\varphi_0}, \varphi_0) = A\left(\frac{1}{L_{\varphi_0}} - \frac{1}{B}\right)$,

and for $\varphi = \varphi_{meas}$: $N_{eq}(L_{meas}, \varphi_{meas}) = N_{eq0}\left(\frac{L_{\varphi_0}}{L_{meas}}\right)^4$

parameters for approximation: N_{ex}, B, α, L_S, a, φ_0

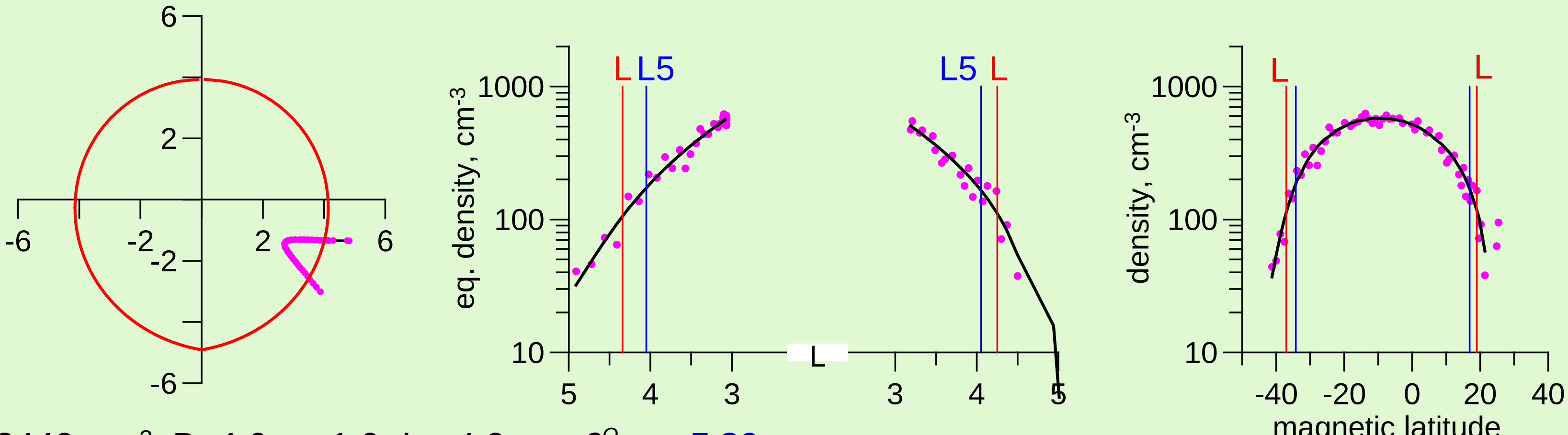
Reconstruction of proton density distribution in the whole plasmasphere using the data of one crossing by INTERBALL 1.

29 December 1995



N_{ex}= 2740 cm^{-3}, B=4.1, α=0.4, L_S=4.78, $\varphi_0=279^O$ **, *a=4.56***

24 June 1996



N_{ex}= 3440 cm^{-3}, B=4.6, α=1.0, L_S=4.9, $\varphi_0=0^O$, ***a=5.29***

Conclusion

The cold plasma data obtained in 1995-2000 on the INTERBALL 1 spacecraft were used for the development of semi-empirical model of the Earth's plasmasphere.

- The 2D physics-based model was developed, which used data on a single pass of the satellite through the plasmasphere to restore the plasma distribution in the entire meridional plane.

- This model is now expanded into 3D one using a simple equation for plasmapause position. 6 parameters with clear physical sense are used to describe cold plasma distribution in the whole plasmasphere.

Thank you!