Ionospheric Langmuir probe electron temperature asymmetry and magnetic field orientation

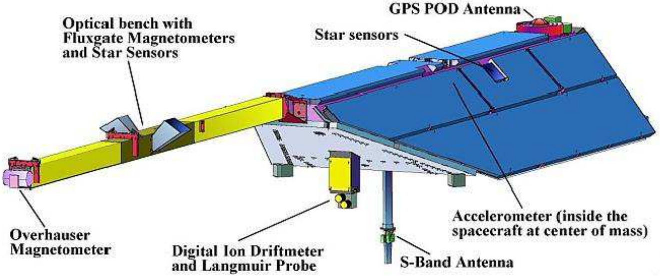
Richard Marchand
Department of Physics, University of Alberta

CAP Congress, Ottawa 2016

Thanks to Claudia Stolle GFZ for valuable input

Outline

CHAMP[1]

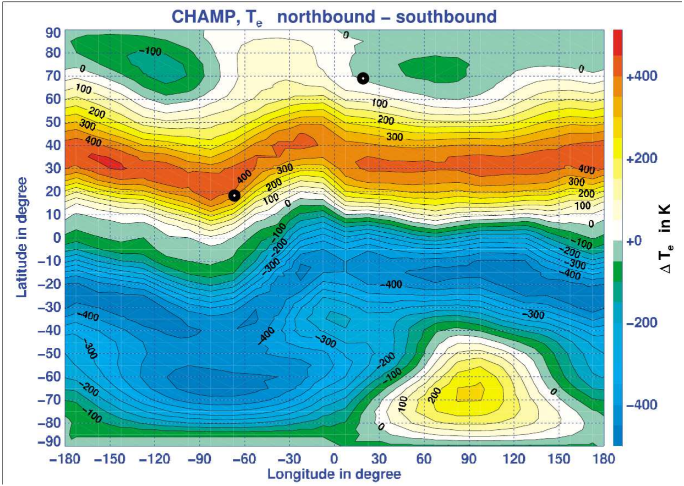


[1] http://op.gfz-potsdam.de/champ/systems/main_SYSTEMS.html

Mission

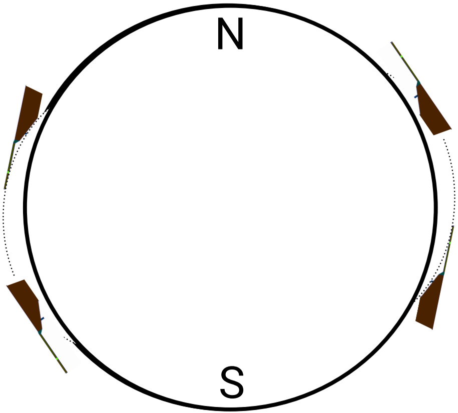
- In orbit from July 15, 2000 until September 19, 2010
- Map Earth magnetic and gravitational fields.
- Atmospheric research
- Monitor ionospheric plasma parameters: n_e, T_e.

Problem: Electron temperature anisotropy[2]



[2]Radio Science, VOL. 45, RS6020, doi:10.1029/2010RS004445, 2010

Hypothesis



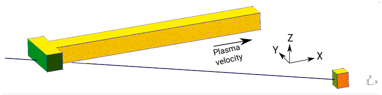
The distribution function of collected electrons depend on whether or not the Planar Langmuir Probe (PLP) is "magnetically connected" with other upstream satellite components.

Numerical approach - PTetra[1]

- Fully kinetic PIC with physical charges and masses.
- Explicit, electrostatic.
- Unstructured adaptive tetrahedral mesh.
- Arbitrary distribution functions of background particles.
- Photoelectron and secondary electron emission.
- Optional biasing of selected satellite components.
- Null collision model of charge exchange collisions.
- Single-processor and multi-processor (MPI) versions.
- 1^{st} order perturbed magnetic fields.
- Extended to account for electrons or ions injection:
  - from any number of satellite components,
  - with arbitrary particle distribution functions.

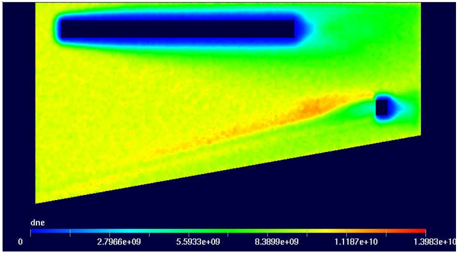
[1] Marchand, IEEE Trans. Plasma Sci., Vol. 40, 2012

Geometry and simulation parameters

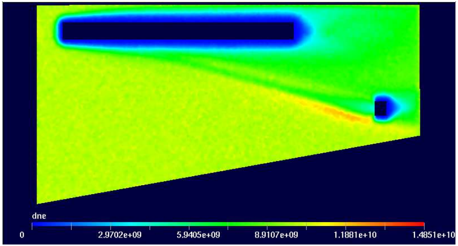


$n_e = n_i$	$10^{10}\ \mathrm{m}^{-3}$
$T_e = T_i$	0.1 eV
ion species	100% H^+
$\vec{B}$	$(36.6,\ 0,\ \pm 8.56)\ \mu\mathrm{T}$
electron plasma frequency	$5.64 \times 10^6 \mathrm{s}^{-1}$
electron thermal Larmor radius ρ_e	2.84 cm
ion thermal Larmor radius ρ_i	1.21 m
electron Debye length λ_{De}	2.35 cm
plasma ram velocity $\vec{v}_r$	$(7673,\ 0,\ 0)\ \mathrm{m/s}$

n_e at steady state



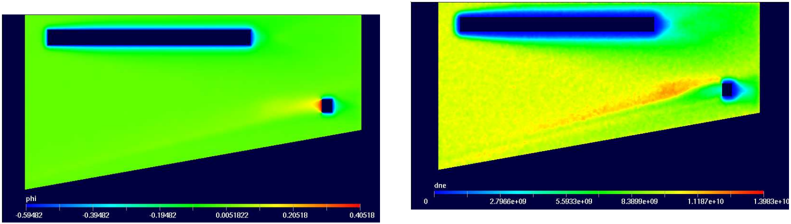
PLP not magnetically connected with the boom.



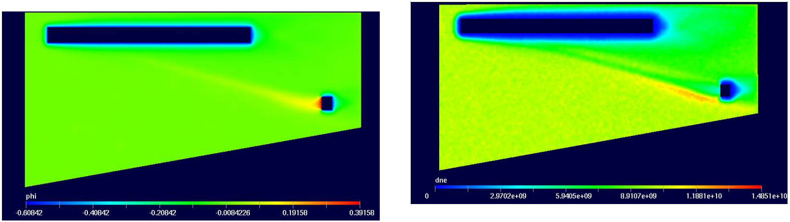
PLP magnetically connected with the boom.

Computed with $V_{bias} = 1$ V.

Steady state with $V = 1.$ V

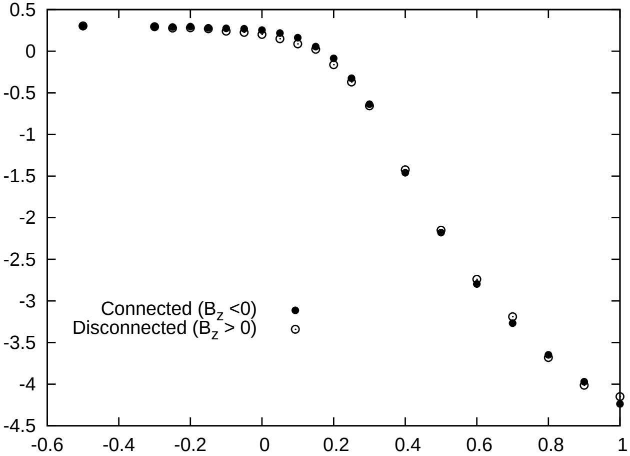


ϕ and n_e With magnetic connection



ϕ and n_e Without magnetic connection

Computed characteristics



Fit

An approximate equation for the PLP characteristic was derived by Ruther, et al.[3]

$$I_P = -e n_e v_{orbit} A_P \left[\frac{\frac{A_P}{A_{Se}} + \frac{A_{Si}}{A_{Se}}}{\frac{A_P}{A_{Se}} + \mathrm{e}^{-\frac{eV}{kT_e}}} - 1 \right], \qquad (1)$$

where

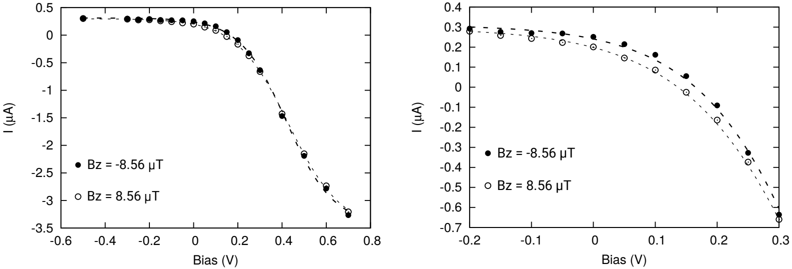
- e is the elementary charge,
- A_P is the probe area,
- A_{Se} and A_{Si} are respectively the effective satellite electron and ion collection areas (excluding PLP),
- v_{orbit} is the satellite orbital speed.

[3] Radio Science, VOL. 45, RS6020, doi:10.1029/2010RS004445, 2010

Monte Carlo fit

- Equation 1 is an equation for I_P vs. V depending nonlinearly on four adjustable parameters α_{1-4}.
  $\alpha_1 = en_e v_{orbit} A_P \ \mu\mathrm{A}$
  $\alpha_2 = (A_P + A_{Si})/A_{Se}$
  $\alpha_3 = A_P/A_{Se}$
  $\alpha_4 = T_e$ (eV)
- An absolute minimum is found with a straightforward Monte Carlo minimization of the square difference between the analytic and computed characteristics:

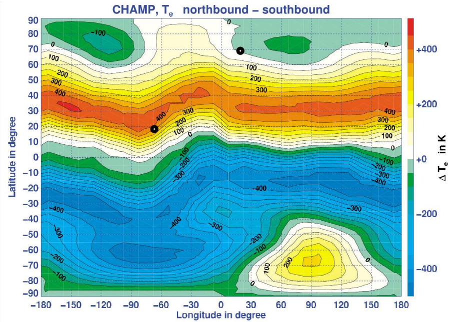
Fitted characteristics

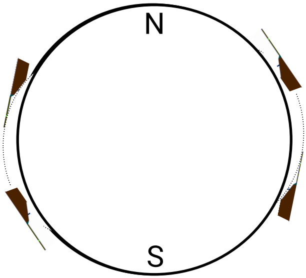


$$I_P = -en_e v_{orbit} A_P \left[\frac{\frac{A_P}{A_{Se}} + \frac{A_{Si}}{A_{Se}}}{\frac{A_P}{A_{Se}} + \mathrm{e}^{-\frac{eV}{kT_e}}} - 1 \right]$$

$\alpha_{1-4} \backslash B_z$	$8.56\mu\mathrm{T}$ disconnected	$-8.56\mu\mathrm{T}$ connected
$\alpha_1 = en_e v_{orbit} A_P$ $\mu\mathrm{A}$	0.2976	0.3112
$\alpha_2 = (A_P + A_{Si})/A_{Se}$	0.3433	0.2230
$\alpha_3 = A_{Si}/A_{Se}$	0.02671	0.01908
$\alpha_4 = T_e$ (eV)	0.1187	0.1060

Comparison with observation





- In the northern hemisphere, northbound - southbound $\Leftrightarrow$ disconnected - connected, $\Rightarrow \Delta T_e \simeq 0.013$ eV $\simeq 150$ K.
- This agrees qualitatively with observation at mid-latitudes.
- Quantitative agreement is also found within a factor $\sim 2 - 3$.

Summary

- Kinetic simulations were made to understand observed mid-latitude electron temperature northbound and southbound legs of the CHAMP orbit.
- "Magnetic connection" of the Planar Langmuir Probe (PLP) with other satellite components affects computed characteristics, and inferred temperatures.
- Differences between northbound and southbound inferred temperatures agree qualitatively with observation.
- Quantitatively computed differences compare with observation within a factor $\sim 2-3$.

Caveat:

- The anisotropy reverses in polar regions where $\vec{B}$ is nearly vertical.
- This could be due to physical processes not included in the simulations, such as incident energetic particle beams, non Maxwellian electron distributions.