Ionospheric Langmuir probe electron temperature asymmetry and magnetic field orientation

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Outline

1. CHAMP electron temperature anisotropy
2. Numerical approach
3. Simulation results
4. Summary
Ionospheric electron temperature

Outline

$T_e$ anisotropy

Numerical approach

Results

Summary

CHAMP

1http://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

Outline

$T_e$ anisotropy
Numerical approach
Results
Summary

\[\text{CHAMP, } T_e \text{ northbound – southbound}\]

$\Delta T_e \text{ in K}$

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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

- 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.
- 1st order perturbed magnetic fields.
- Extended to account for electrons or ions injection:
  - from any number of satellite components,
  - with arbitrary particle distribution functions.

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### Geometry and simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_e = n_i$</td>
<td>$10^{10}$ m$^{-3}$</td>
</tr>
<tr>
<td>$T_e = T_i$</td>
<td>0.1 eV</td>
</tr>
<tr>
<td>Ion species</td>
<td>100% $H^+$</td>
</tr>
<tr>
<td>$\vec{B}$</td>
<td>(36.6, 0, ± 8.56) $\mu$T</td>
</tr>
<tr>
<td>Electron plasma frequency</td>
<td>$5.64 \times 10^6$ s$^{-1}$</td>
</tr>
<tr>
<td>Electron thermal Larmor radius $\rho_e$</td>
<td>2.84 cm</td>
</tr>
<tr>
<td>Ion thermal Larmor radius $\rho_i$</td>
<td>1.21 m</td>
</tr>
<tr>
<td>Electron Debye length $\lambda_{De}$</td>
<td>2.35 cm</td>
</tr>
<tr>
<td>Plasma ram velocity $\vec{v}_r$</td>
<td>(7673, 0, 0) m/s</td>
</tr>
</tbody>
</table>
$n_e$ 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

Connected ($B_z < 0$)
Disconnected ($B_z > 0$)
An approximate equation for the PLP characteristic was derived by Ruther, et al.\(^3\)

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

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),
- \(v_{\text{orbit}}\) is the satellite orbital speed.

• Equation 1 is an equation for $I_P$ vs. $V$ depending nonlinearly on four adjustable parameters $\alpha_{1-4}$.
  $\alpha_1 = e n_e \nu_{\text{orbit}} A_P \mu A$
  $\alpha_2 = (A_P + A_{Si})/A_{Se}$
  $\alpha_3 = A_P/A_{Se}$
  $\alpha_4 = T_e \text{ (eV)}$

• An absolute minimum is found with a straightforward Monte Carlo minimization of the square difference between the analytic and computed characteristics:
Fitted characteristics

\[ I_P = -e n_e v_{\text{orbit}} A_P \left[ \frac{A_P/A_{Se} + A_{Si}/A_{Se}}{A_P/A_{Se} + e^{-\frac{eV}{kT_e}}} - 1 \right] \]

<table>
<thead>
<tr>
<th>( \alpha_{1-4}/B_z )</th>
<th>8.56 ( \mu T )</th>
<th>-8.56 ( \mu T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>disconnected</td>
<td>connected</td>
<td></td>
</tr>
<tr>
<td>( \alpha_1 = e n_e v_{\text{orbit}} A_P \ \mu A )</td>
<td>0.2976</td>
<td>0.3112</td>
</tr>
<tr>
<td>( \alpha_2 = (A_P + A_{Si})/A_{Se} )</td>
<td>0.3433</td>
<td>0.2230</td>
</tr>
<tr>
<td>( \alpha_3 = A_{Si}/A_{Se} )</td>
<td>0.02671</td>
<td>0.01908</td>
</tr>
<tr>
<td>( \alpha_4 = T_e \ (\text{eV}) )</td>
<td>0.1187</td>
<td>0.1060</td>
</tr>
</tbody>
</table>
• In the northern hemisphere, northbound - southbound ⇔ disconnected - connected, ⇒ \( \Delta T_e \approx 0.013 \text{ eV} \approx 150 \text{ K} \).

• 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.