Geotail CPI Survey Plots

L. A. Frank, K. L. Ackerson, W. R. Paterson, R. L. Dyson, G. T. Parmentier, and G. L. Pickett

1 Summary

The Comprehensive Plasma Instrumentation (CPI) for the Geotail spacecraft consists of three plasma analyzers: (1) an electrostatic analyzer for hot electrons and ions, (2) a complementary electrostatic analyzer for cool plasmas with high bulk speeds such as those found within the solar wind and magnetosheath, and (3) an ion composition analyzer for identification of ion species such as H^+, He^+, He^{++}, and O^+. The energy-per-unit charge (E/Q) ranges for these analyzers are 1.3 V to 48.2 kV, 145 V to 6830 V, and 1.3 V to 48.2 kV, respectively. Three-dimensional velocity distributions of the ions and electrons are acquired for the first time in the distant magnetotail and are sufficiently accurate to separate $\vec{E} \times \vec{B}$ drifts from field-aligned flows associated with currents. Among the many specific scientific objectives of the plasma observations are the relative importance of ionospheric and solar wind sources, searches for plasmoids and flux ropes, current-sheet acceleration of plasmas, and convection and current systems in the magnetotail.

2 Description of Instrumentation

The Comprehensive Plasma Instrumentation is distributed into three separate mechanical housings. CPI-HS is the Hot Plasma Analyzer and the Solar Wind Ion Analyzer, and CPI-IC is the Ion Composition Analyzer. CPI-E contains the interface circuits to the spacecraft and the microprocessor responsible for overall control of the operation of the instrument. A simplified block diagram is included in Figure 1. The instrumentation is equipped with three Harris 80C85 microprocessors, each with read-only memory (ROM) and random-access memory (RAM) with capacities of 16 kilobytes and 48 kilobytes, respectively. The total mass and average power of the plasma instrumentation is 17.5 kg and 10.5 W, respectively. The telemetry allotment is 4.6 kilobits/s and is extended by runlength coding in the instrument to about 8.2 kilobits/s.

The configuration diagram for CPI-HS is shown in Figure 2. The Hot Plasma Analyzer is equipped with three spherical-segment plates. The outer and inner plates are grounded, and the center plate is supplied with a programmable series of voltages, 65 mV to 2.4 kV, in order to provide E/Q analyses of the ions and electrons. The radius of curvature R of the center plate is 10.2 cm and the analyzer constant, $R/(2\Delta R)$, is 20 for electrons and positive ions. The 64 E/Q passbands for the range 1.3V $\leq$ E/Q $\leq$ 48.2kV are identified in Table 1. The inner and outer channels are the positive ion and electron analyzers, respectively. Each of these two analyzers is serviced with 9 continuous-channel electron multipliers in order to divide the fan-shaped acceptance angle into 9 individual segments. These sensors are Galileo Electro-Optics Spiraltrons with either 1 mm or 3 mm diameter acceptance apertures, the outputs of which are fed into individual AMPTEK Inc. model A111F PAD amplifier-discriminators. The Spiraltron bias voltages are controlled by ground commands to any one of 32 voltage levels between +1690 to +3400 V (electron sensors) and −1718 to −3450 V (positive ion sensors). Considerable design effort was expended in shaping the analyzer fields-of-view and in maintaining approximately equal geometric factors and E/Q resolutions for the two sets of nine sensors. These goals were accomplished with a fence at the entrance apertures of the electrostatic analyzers, tailored angular length (analyzer arc angle) from entrance to exit apertures, and aperture plates at the sensors. In addition the concave surfaces of the spherical-segment plates were machined with sawtooth serrations of 1-mm depth in order to suppress the ultraviolet (primarily solar Lyman$-\alpha$) and electron scattering along the plates into the sensors.

The fields-of-view, energy resolutions and provisional geometric factors are derived from ray tracing and laboratory calibrations and are tabulated in Table 2. The provisional geometric factors are to be refined with postlaunch data. The latitude θ is taken with respect to the spin axis of the spacecraft with 0° in a direction parallel to the spin axis and viewing generally toward the south ecliptic pole. The azimuthal range of ϕ is given in the spacecraft spherical coordinate system. The meridional plane at $\phi = 0°$ is parallel to the normal to the entrance aperture of the electrostatic analyzers. For example, the instantaneous field-of-view for electron sensor E1 is the solid angle within $4° \leq \theta \leq 38°$ and $31° \leq \phi \leq 81°$. Note that the total coverage of latitude is 4° to 176° and allows sampling of all but 0.3% of the $4\pi-$sr solid angle for particle velocity vectors at the spacecraft position. This is an important feature for accurate determination of the three-dimensional velocity distributions.

The operation of the Hot Plasma Analyzer is extremely flexible and is controlled by uplinked commands to the instrument microprocessors. A frequent operating mode for measuring the three-dimensional velocity distributions of positive ions and electrons is the division of one spacecraft rotation period (3 s) into eight equal intervals (azimuthal sectors). Four E/Q passbands are consecutively sampled in each of these azimuthal sectors. Every other passband in the range 22.2 V to 48.2 kV (see Table 1) is used. Thus a 1728-sample determination of each of the ion and electron intensities over the above E/Q range is acquired in 18 s. The repetition rate is 21 s because 2304 samples each of the ion and electron velocity distributions, 1.3V $\leq$ E/Q $\leq$ 230V, are gathered each $192s$ in order to characterize the spacecraft potential, the secondary electron environment, and ambient cold plasmas.

The configuration of the Solar Wind Ion Analyzer is also shown in Figure 2. The twelve sets of sensors and amplifier-discriminators are the same types as those employed for the Hot Plasma Analyzer. The bias voltage for the Spiraltrons can be varied from -1975 V to -3940 V in 32 increments by ground command. The analyzer arc angle is 75° and the analyzer constant is 42. A programmed series of potentials ranging from 3.4 V to 163 V on the outer plate with the inner plate grounded provides measurements of positive ions with 144V $\leq$ E/Q $\leq$ 6825V within a maximum of 64 passbands. These passbands are listed in Table 3. The total latitudinal span of the field-of-view is $60^\circ \leq \theta \leq 120^\circ$ which is divided into 12 equal, contiguous segments of 5° with the use of 12 sensors at the exit aperture of the electrostatic analyzer. The angular coverages, energy resolutions, and provisional geometric factors for the 12 sensors are tabulated in Table 4.

Operation of the Solar Wind Ion Analyzer is flexible via ground commands. A current operating mode provides division of the azimuthal (spin) sector $\phi_s = 294.5^\circ$ to 90.0° into 42 equal, contiguous segments where $\phi_s = 0^\circ$ is the direction to the sun. Thus the field-of-view consists of 504 contiguous solid angles, 12(latitude) $\times$ 42(azimuth). These fields-of-view and the E/Q passbands are interleaved to achieve 7560 samples of the ion velocity distribution once each 48 s. The odd-numbered passbands as listed in Table 3 are employed for this particular mode of operation.

3 Description of the Solar Wind Ion Survey Spectrogram

The responses of the Solar Wind Ion Analyzer were averaged for about 50 minutes. For each of the 32 E/Q passbands, the responses of all twelve sensors in all sectors were scanned, and the peak response for each passband was determined. The logarithm (base 10) of each of these responses was color coded and displayed in the Energy-time spectrogram.

Velocity moments of these averaged distribution functions were integrated to obtain the ion number density and flow velocity:

$$n = \int f d\vec{v} = \text{ number density}$$

$$\vec{u} = \frac{1}{n} \int f \vec{v} d\vec{v} = \text{flow velocity}$$

The number density is plotted in the second panel and the magnitude of the flow velocity is shown in the third panel. The polar angles of the flow velocity, ϕ ($\phi = 180°$ is anti-sunward) and θ ($\theta = 90°$ is the S/C spin plane) are plotted in fourth panel.

The kinetic temperature was computed from the distribution function by integrating:

$$T = \frac{m}{3Kn} \int |\vec{u} - \vec{v}|^2 f d\vec{v} = \text{kinetic temperature}$$

The CPI solar wind ion analyzer is an E/Q analyzer and the initial distribution functions were calculated assuming that the plasma is H^+. Care must be taken when multi-component plasmas are present. If He^{++} is present and is flowing with the same speed as the H^+ component, it will contribute to the distribution function at twice the velocity (four times the energy) of the H^+. To facilitate the automated processing of these data the above integral was evaluated between $|\vec{v}_{min}| = 171$km/s and $|\vec{v}_{max}| = 1.35 \times |\vec{u}|$. The resulting temperatures produce excellent fits to the observations. When He^{++} is present the distribution functions are consistent with an He^{++} temperature, $T_{He^{++}} = 4 \times T_{H^+}$, *i.e.*, the H^+ and He^{++} have similar thermal velocities.

4 Description of the Hot Plasma Survey Plot

The Hot Plasma analyzer measures the intensities of electrically charged particles as functions of particle energy and direction. Measurements of electrons and positive ions are acquired simultaneously. This analyzer is one element of the Comprehensive Plasma Instrumentation (CPI) on board the Geotail spacecraft. Detailed descriptions of the Hot Plasma analyzer (HP), the Solar Wind analyzer (SW), the Ion Composition analyzer (IC), and the associated electronics package that comprise the Comprehensive Plasma Instrumentation are provided in the Description of Instrumentation.

Measurements from the Hot Plasma analyzer are available at this Web site in a graphical survey format. This format is designed to provide convenient access to the observations. Each survey plot is a five-day record of the electron and ion intensities and several parameters derived from those intensities. The measurements are given in a sequence of five panels. From top to bottom the panels display:

1. N [cm^{-3}], the ion number density.
2. V_X [km-s^{-1}], the component of the ion bulk-flow velocity along the Earth-Sun line. Positive flow is towards the sun.
3. T_i and T_e [K], the respective temperatures of ions and electrons.
4. The intensities of positive ions as a function of particle energy.
5. The intensities of electrons as a function of particle energy.

The particle intensities given in panels 4 and 5 are five-minute accumulations from the ion and electron sensors that view the ecliptic plane. This plane is perpendicular to the spin axis of the spacecraft, and the intensities are summed over eight equally spaced spin sectors. The particle intensities are color coded according to the logarithmic color bar on the right-hand side of the figure which has separate scales for ions and electrons. Particle energies-per-charge (E/Q, Volts) are indicated by the logarithmic scale on the ordinates of the ion and electron panels. Dates corresponding to the major tick marks on the abscissa are shown at the bottom of the display. Minor tick marks are given at four-hour intervals. The projection of the Geotail orbit in the ecliptic plane is shown for reference at the top of the display. The beginning of each day is marked with a dot, and the first day of the five-day sequence is highlighted.

The plasma parameters given in the first three panels of the survey display are computed for particles with energies-per-charge in the range 50 V to 48 kV. The ions are assumed to be protons. The parameters are computed using five-minute accumulations from the electron and ion sensors that view the ecliptic plane. Thus, the number density, the V_X component of the flow, and the temperatures given here are equivalent to those that would be gained with a two-dimensional plasma analyzer.

5 Acknowledgments

The authors extremely appreciate the efforts of D. W. Burke, P. K. Hardebeck, J. D. Harvey, L. M. Henry, K. A. Hunt, P. S. Reilly, and J. A. Sartain from The University of Iowa, and M. H. Acuña, J. P. Galloway, D. E. Galoppo, M. M. Grant, and K. O. Sizemore and many other persons of the Goddard Space Flight Center/NASA in helping us implement this investigation. Invaluable assistance and great courtesy were given to us in prelaunch integration and testing and in postlaunch operations of our instrument by H. Hayakawa, S. Machida, T. Mukai, M. Nakamura, A. Nishida, T. Obara, K. Tsuruda, and K. Uesugi at the Institute of Space and Astronautical Science, J. Ishida of NEC, and a large number of their colleagues. For a more complete discussion of the Comprehensive Plasma Instrumentation for the Geotail spacecraft see *J. Geomag. Geoelectr.*, **46**, 23–37, 1994.

6 Tables

Table 1. Hot Plasma Analyzer and Ion Composition Analyzer Center of E/Q Passbands

Passband No.	E/Q	Passband No.	E/Q	Passband No.	E/Q
0	1.3 V	22	51.2 V	43	1.71 kV

1	1.5	23	60.5	44	2.02
2	1.8	24	71.5	45	2.39
3	2.1	25	84.5	46	2.82
4	2.5	26	100	47	3.33
5	3.0	27	118	48	3.94
6	3.5	28	140	49	4.65
7	4.2	29	165	50	5.50
8	4.9	30	195	51	6.50
9	5.8	31	230	52	7.68
10	6.9	32	322	53	9.08
11	8.2	33	322	54	10.7
12	9.6	34	380	55	12.7
13	11.4	35	449	56	15.0
14	13.5	36	531	57	17.7
15	15.9	37	627	58	20.9
16	18.8	38	741	59	24.7
17	22.2	39	876	60	29.2
18	26.2	40	1.04 kV	61	34.5
19	31.0	41	1.22	62	40.8
20	36.7	42	1.45	63	48.2
21	43.3				

Table 2. Hot Plasma Analyzer
Nominal Performance Parameters

Sensor	Analyzer arc angle (deg.)	Angular Coverage theta	Angular Coverage phi (deg.)	Energy Resolution dE/E	Geometric Factor cm2-sr-eV/eV
E1	75	4, 38	-31, 81	0.10	8.0 x 10^{-6}
E2	70	22, 48	-20, 45	0.13	1.8 x 10^{-5}
E3	70	42, 66	-33, 23	0.08	2.1 x 10^{-5}
E4	65	57, 84	-22, 11	0.09	2.0 x 10^{-5}
E5	60	74,106	-12, 5	0.10	1.8 x 10^{-5}
E6	65	96,123	-22, 11	0.09	2.0 x 10^{-5}
E7	70	114,138	-33, 23	0.08	2.1 x 10^{-5}
E8	70	132,158	-20, 45	0.13	1.8 x 10^{-5}
E9	75	142,176	-31, 81	0.10	8.0 x 10^{-6}
P1	75	4, 35	-66, 81	0.09	4.8 x 10^{-5}
P2	70	22, 48	-19, 44	0.12	5.9 x 10^{-5}
P3	70	42, 66	-33, 22	0.08	5.9 x 10^{-5}
P4	65	57, 84	-22, 10	0.09	6.5 x 10^{-5}
P5	60	74,106	-12, 4	0.10	6.5 x 10^{-5}
P6	65	96,123	-22, 10	0.09	6.5 x 10^{-5}
P7	70	114,138	-33, 22	0.08	5.9 x 10^{-5}
P8	70	132,158	-19, 44	0.12	5.9 x 10^{-5}
P9	75	145,176	-66, 81	0.09	4.8 x 10^{-5}

Table 3. Solar Wind Ion Analyzer
Center of E/Q Passbands

Passband No.	E/Q	Passband No.	E/Q	Passband No.	E/Q
0	144 V	22	555 V	43	2010 V
1	153	23	590	44	2133
2	163	24	627	45	2270
3	173	25	667	46	2410
4	184	26	709	47	2560
5	196	27	753	48	2725
6	208	28	801	49	2900
7	221	29	852	50	3080
8	235	30	905	51	3270
9	250	31	962	52	3480
10	266	32	1020	53	3700
11	283	33	1090	54	3930
12	301	34	1160	55	4180
13	320	35	1230	56	4450
14	340	36	1310	57	4730
15	361	37	1390	58	5025
16	384	38	1480	59	5340
17	408	39	1570	60	5680
18	434	40	1670	61	6040
19	462	41	1775	62	6420
20	491	42	1890	63	6825
21	522				

Table 4. Solar Wind Ion Analyzer
Nominal Performance Parameters

Sensor	Angular Coverage theta	phi (deg.)	Energy Resolution dE/E	Geometric Factor cm2-sr-eV/eV
S1	60,66	-8,7	0.034	3.3 x 10^{-6}
S2	65,71	-7,6	0.034	3.5 x 10^{-6}
S3	70,76	-6,5	0.034	3.6 x 10^{-6}
S4	75,81	-5,4	0.034	3.6 x 10^{-6}
S5	79,86	-4,3	0.034	3.7 x 10^{-6}
S6	84,91	-3,2	0.034	3.7 x 10^{-6}
S7	89,96	-3,2	0.034	3.7 x 10^{-6}
S8	94,101	-4,3	0.034	3.7 x 10^{-6}
S9	99,105	-5,4	0.034	3.6 x 10^{-6}
S10	104,110	-6,5	0.034	3.6 x 10^{-6}
S11	109,115	-7,6	0.034	3.5 x 10^{-6}
S12	114,120	-8,7	0.034	3.3 x 10^{-6}