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GEOTAIL MCA Plasma Wave Data Analysis
NASA Grant NAG5-2346
Principal Investigator: Roger R. Anderson

Annual Performance Report
August 15, 1993 - August 14, 1994

This report is for NASA Grant NAG 5-2346, GEOTAIL MCA Plasma Wave Data Analysis. This report covers the time period August 15, 1993, to August 14, 1994.

NASA Grant NAG 5-2346 supports the data analysis effort at The University of Iowa for the GEOTAIL Multi-Channel Analyzer (MCA) which is a part of the GEOTAIL Plasma Wave Instrument (PWI). At the beginning of this reporting period we had just begun to receive our GEOTAIL Sirius data on CD-ROMs. Much programming effort went into adapting and refining the data analysis programs to include the CD-ROM inputs. Programs were also developed to display the high-frequency-resolution PWI Sweep Frequency Analyzer (SFA) data and to include in all the various plot products the electron cyclotron frequency derived from the magnitude of the magnetic field extracted from the GEOTAIL Magnetic Field (MGF) data included in the GEOTAIL Sirius data. We also developed programs to use the MGF data residing in the Institute of Space and Astronautical Science (ISAS) GEOTAIL Scientific Data Base (SDB). Our programmers also developed programs and provided technical support for the GEOTAIL data analysis efforts of Co-Investigator William W. L. Taylor at Nichols Research Corporation (NRC). At the end of this report we have included brief summaries of the NRC effort and the progress being made.

The GEOTAIL Plasma Wave Instrument and the Multi-Channel Analyzer have worked properly since the launch on July 24, 1992. Many interesting and exciting plasma wave phenomena have been detected and studied during GEOTAIL's many traversals of the Earth's geomagnetic tail and magnetosphere. These phenomena are discussed in the talks and papers reported below.

Roger R. Anderson attended and participated in the XXIVth General Assembly of the International Union of Radio Science held in Kyoto, Japan, on August 25 - September 2, 1993. GEOTAIL Plasma Wave Instrument (PWI) data were presented in the following papers:

(NASA-CR-197022) GEOTAIL MCA PLASMA WAVE DATA ANALYSIS Annual Report, 15 Aug. 1993 - 14 Aug. 1994 (Iowa Univ.) 14 p

N95-14798

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AKR and Auroral Myriametric Radiation Observed by GEOTAIL

H Matsumoto[1], I Nagano[2], R R Anderson[3], H Kojima[1], K Hashimoto[4], M Tsutsui[5], T Okada[6], I Kimura[1], Y Omura[1], M Okada[1], and S Chikuba[1]
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Introduction

Characteristics of Auroral Kilometric Radiation (AKR) and associated low frequency radiation, which we call Auroral Myriametric Radiation (AMR), observed by the GEOTAIL Plasma Wave Instrument (PWI) are reported. AMR is low-frequency radiation which correlate with simultaneously observed AKR emissions. Filbert and Kellogg [1] reported characteristics of the low-frequency radiation in a frequency range of 10 - 40 kHz. Our observations show the frequencies of such correlated emissions become as low as 1 kHz.

Observations

One of receivers of the PWI, Sweep Frequency Analyzer (SFA) is used in this report. The SFA provides amplitude spectral information. Typical SFA data observed on Oct. 18, 1992 is shown in the figure below. AKR ranges from around 20 - 500 kHz and associated AMR is observed in 1 - 20 kHz. Good correlations between the two in wider frequency ranges than those of [1] can be seen.

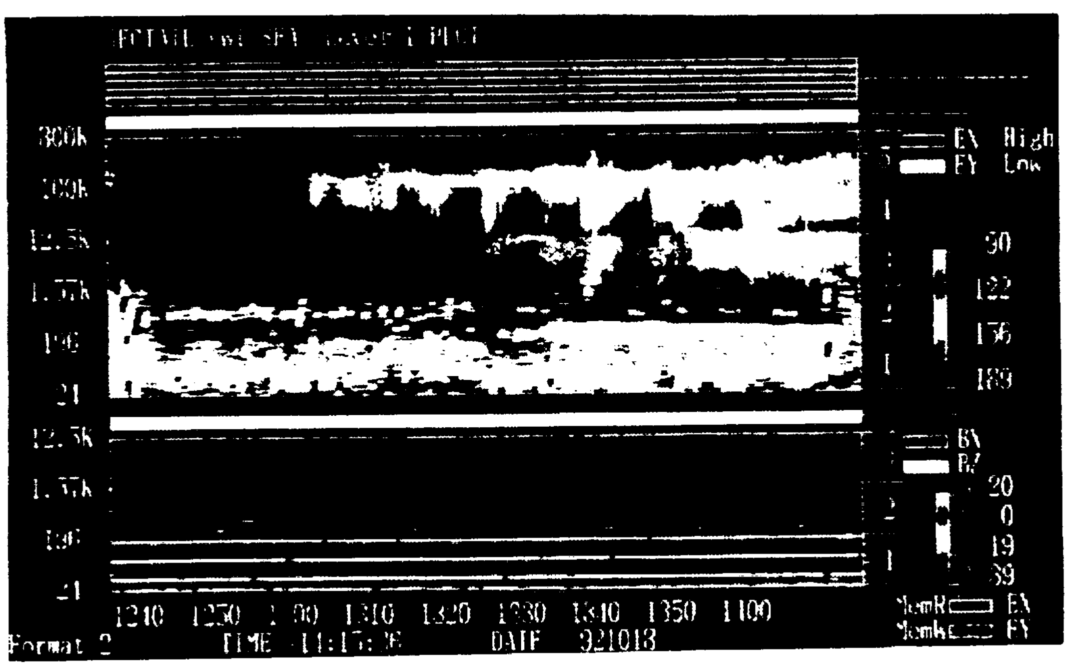
Discussion and Acknowledgements

AMR is not necessarily associated with AKR. Direction findings and investigation of relationship with other observations, magnetic disturbances, etc. are under way.

GEOTAIL PWI team acknowledges ISAS for their support.

Reference

[1] P. C. Filbert and P. J. Kellogg, J. Geophys. Res., 94, 8867, 1989.



ULF Emission-triggered Chorus Observed by the GEOTAIL near the Dayside Magnetopause

H Matsumoto[1], I Nagano[2], R R Anderson[3], H Kojima[1], K Hashimoto[4], M Tsutsui[5], T Okada[6], I Kimura[1], Y Omura[1], M Okada[1], H Murata[2], Y Takeshita[1], and T Miyatake[1], T Shiozaki[2]

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Introduction

One-to-one correlation phenomena between chorus emissions and ULF emissions were simultaneously observed by the GEOTAIL Plasma Wave Instrument (PWI) for about 8 hours while the GEOTAIL was skimming near the dayside magnetopause on October 17-18, 1992 (Fig. 1). In this report, the characteristics of the chorus emission, such as the wave normal direction, polarization, refractive index and Poynting flux, are analyzed by Means' method using the wave forms of five components. The relationship between the both emissions are discussed.

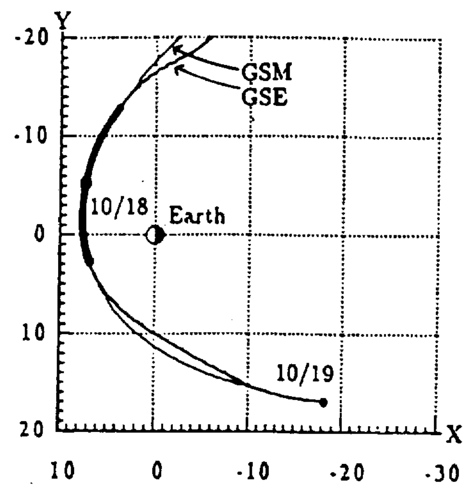

Fig. 1 The orbit of GEOTAIL.
The chorus were observed along the thick line.

Observations

The Wave Form Capture (WFC) on board, which covers in the frequency range from 10Hz to 4kHz, provides the five components of the electromagnetic wave forms (two electric and three magnetic components) for 8.7 seconds in 5 minutes intervals for the memory mode. Fig. 2 shows an example of the spectrum of the ULF emission-triggered chorus. The chorus were mainly composed of the rising tone. The intensities up to 10pT/ Hz were often detected. The distribution of center frequency of the chorus varied from 0.36fH to 0.14fH, where fH is a local gyro-frequency during the observation.

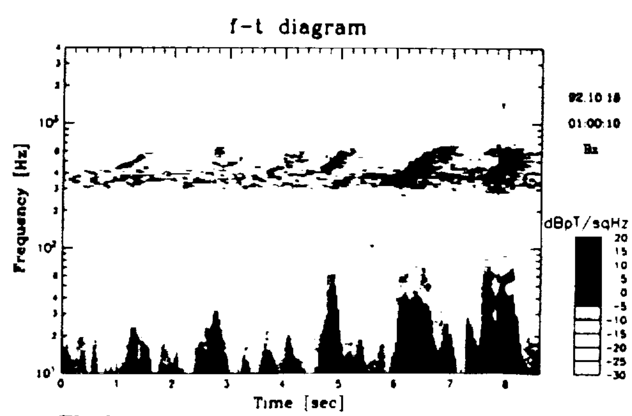

Fig. 2 An example of the spectrum of the emissions observed by the WFC on board the GEOTAIL.

Conclusions

The GEOTAIL observed the ULF emission-triggered chorus near the dayside magnetopause. The wave normal directions of the chorus are not always parallel to the earth's magnetic field.

Plasma Wave Characteristics in the Distant Magnetotail

H Matsumoto[1], I Nagano[2], R R Anderson[3], H Kojima[1], K Hashimoto[4], M Tsutsui[5], T Okada[6], I Kimura[1], Y Omura[1], M Okada[1], O Nishimura[1], and A Fujita[1]
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Introduction

GEOTAIL spacecraft has already experienced the distant magnetotail twice up to now. The onboard plasma wave receivers revealed high wave activities in the distant tail region. In the present paper, we discuss how the wave characteristics in the distant tail change from one region to other using GEOTAIL plasma wave data.

Observation

In the distant tail, GEOTAIL passed through the magnetosheath, the mantle, the tail lobe, the plasma sheet boundary layer, the plasma sheet and occasionally the neutral sheet for a short period. Using the fluxgate magnetometer data and the electron density estimated from lower cut off frequencies of the observed continuum radiation, we could discuss the characteristic wave phenomena in each region.

Figure 1 shows BEN-like broad band noises are enhanced when the ambient magnetic field showed such variation as if the plasmoid has passed the spacecraft. It is also interesting that the wave activities are suddenly weakened when GEOTAIL crossed the neutral sheet.

We will summarize the plasma wave observation results in the distant tail and discuss the characteristic of wave activities in more detail.

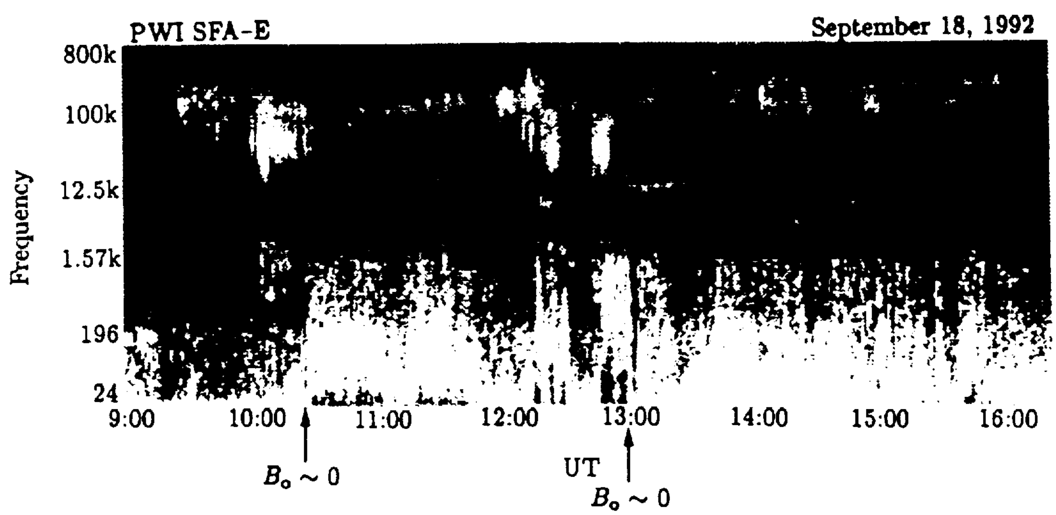

Fig. 1: Example of observed plasma wave spectra in the distant magnetotail

Measurements of Antenna Sheath Impedance by GEOTAIL Spacecraft

H Matsumoto[1], I Nagano[2], R R Anderson[3], H Kojima[1], K Hashimoto[4], M Tsutsui[5], T Okada[6], I Kimura[1], Y Omura[1], M Okada[1], and H Miyatake[1]
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Introduction

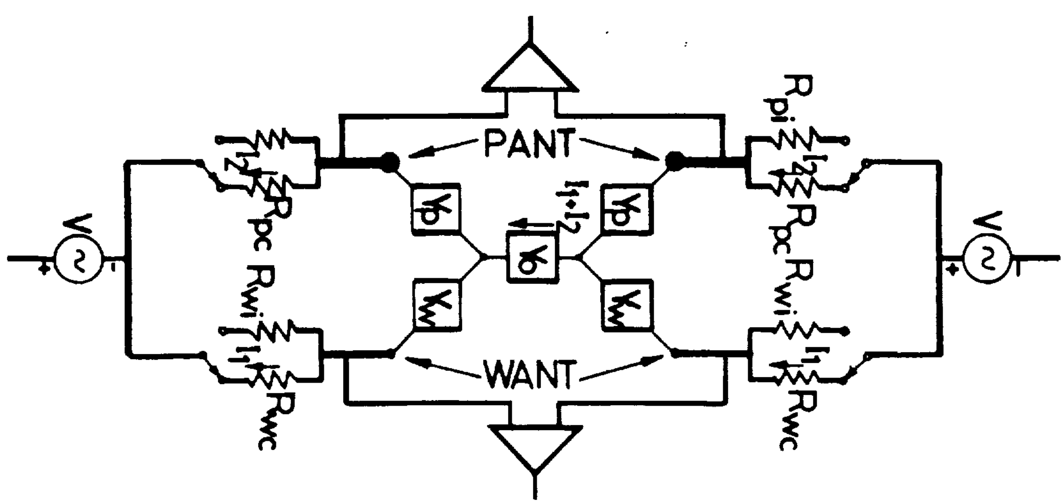
For estimation of absolute values of electric field of plasma waves in space, it is necessary to get a sheath impedance around an electric antenna. In this paper, a method of measuring the sheath impedances around two sets of dipole antenna on board GEOTAIL spacecraft and measured results are reported.

A method of measuring antenna sheath impedance by GEOTAIL

The GEOTAIL spacecraft has a function of waveform capture (WFC) for plasma wave observations. Electric circuits for signal calibrations of the WFC data can be used for the measurement of the sheath impedance around the dipole antenna. An equivalent circuit for the sheath impedance measurement around the two sets of dipole antenna is given in the figure. In this circuit, eleven unknown factors are included, and eleven equations were used for solving the admittances around the four antenna elements.

Discussion and conclusions

Obtained result shows consistent values of sheath impedance in connection with surrounding plasma parameters and values in vacuum space. A validity of the equivalent circuit and a possibility of modified circuits are discussed in connection with implications of bias voltage onto the antenna elements.



Characteristics of Antenna Potential Perturbation due to Photo-electron Emission Observed by the GEOTAIL Satellite

H Matsumoto[1], I Nagano[2], R R Anderson[3], H Kojima[1], K Hashimoto[4], M Tsutsui[5], T Okada[6], I Kimura[1], Y Omura[1], M Okada[1], K Tsuruda[7], H Hayadawa[7], M Nakamura[7], A Nishida[7], A Matsuoka[7], S Kokubun[8], and T Yamamoto[8]
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Introduction

Electric potential perturbations were observed in the ELF range by the double probe onboard the GEOTAIL satellite in the magnetosphere. In this paper, some of the characteristic features of such perturbations are presented and their generation mechanism is discussed in terms of the photoelectron emission from the probes and the satellite.

Observations and discussion

The electric potential difference in space is detected by a pair of wire antennas and a pair of sphere probes, and is recorded by the waveform capture of the PWI system. A bias current is fed to each probe from the EFD system to control the probe potential against the ambient plasma potential. Examples of the wave form from the sphere-type double probe are shown in the figure which were recorded during the period 10:30 - 11:30 UT on August 28, 1982. The unit of the horizontal axis is indicated by a bar of 3 sec (spin period of the satellite). Intense perturbations are found to be synchronous with the satellite spin phase angle. The amplitudes of such perturbations and other noises are seen to be controlled by the polarity and amount of the bias current of the double probes. These features of the potential waveforms are interpreted in terms of the effect of the photo electron emitted from the double probe system and the satellite. The charge-up and discharge of the double-probe elements are also thought to be the source of the potential perturbation. The pick-up factor of the probe is expected to be enhanced due to the effect of the bias current.

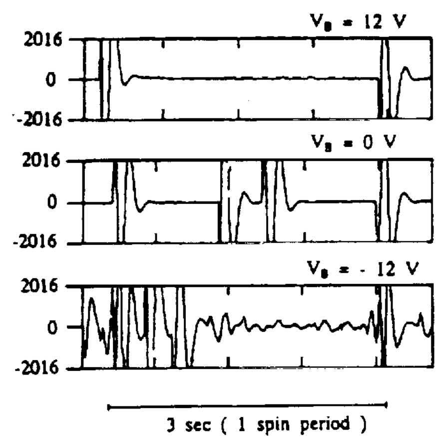

Figure Examples of the waveform from the sphere-type double probe

In December 1993, Roger R. Anderson attended the American Geophysical Union (AGU) Fall Meeting in San Francisco, California, and presented the following paper in the New Results from GEOTAIL Special Session.

<u>Continuum Storms and Other Transient Events Observed by the GEOTAIL Plasma Wave Instrument Multi-Channel Analyzer in the Earth's Geomagnetic Tail</u>

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Isolated bursts of terrestrial myriametric (continuum) radiation which we call "Continuum Storms" have been observed by the GEOTAIL Plasma Wave Instrument (PWI) Multi-Channel Analyzer (MCA) on the average of two to three times per month during the first year of operation. The Continuum Storms display an abrupt onset or increase in the intensity of the continuum radiation in a limited frequency range from at or above 10 kHz to near or below 50 kHz. The duration of the events is typically a few tens of minutes to one or two hours. Some dispersion in the onset is occasion ally observed with the lower frequencies beginning earlier. In the frequency-time spectrograms these continuum storm bursts with dispersion have the distinctive appearance of an airfoil. Examination of the high-frequency resolution PWI Sweep Frequency Analyzer (SFA) data showed that the continuum storm bursts did not have any significant narrowband fine structure. While some of the continuum storm bursts occur simultaneously with Auroral Kilometric Radiation and/or boundary crossings in the geomagnetic tail, many occur alone. The continuum storm bursts have been observed throughout the geomagnetic tail region to distances as far as 210 Re in the distant tail. In fact, they were observed most frequently in June and July 1993 when GEOTAIL was deepest in the tail. If the generation mechanism of these waves is the same as that proposed for other terrestrial and planetary continuum radiation, generation of the waves at or near the plasma frequency implies number densities in the source region of the order of 1 to 40 cm-3 and a sharp density gradient. In the distant tail, the magnetopause could be the source region. We are investigating the possible association between the continuum storm bursts and other geomagnetic activity and indices. The

plasma wave characteristics observed in other transient phenomena such as possible flux transfer events and plasmoids in the distant tail will also be presented.

Roger R. Anderson attended and presented GEOTAIL PWI MCA data in an invited talk "Plasma waves at the Magnetopause" at the AGU Chapman Conference on the Magnetopause held in San Diego, California, from March 14-18, 1994.

Roger R. Anderson attended and presented an contributed talk at the Spring American Geophysical Union Meeting in Baltimore, Maryland, May 23-27, 1994. The title, author and co-authors, and abstract are:

Continued Plasma Wave Observations Deep in the Earth's Geomagnetic Tail From the GEOTAIL PWI Multi-Channel Analyzer

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D A Gurnett (Dept. Physics and Astronomy, The University of Iowa, Iowa City, IA 52242; 319-335-1697; NSI IOWAVE::GURNETT)

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Every pass that GEOTAIL makes into the Earth's deep geomagnetic tail (with apogee distances ranging from 60 Re to 220 Re) continues to yield very interesting plasma wave phenomena detected by the high- time-resolution PWI Multi-Channel Analyzer. Strong Electron Plasma Oscillations (EPO) have been observed simultaneously with low- frequency electromagnetic waves at Plasma Sheet Boundary Layer - Lobe interfaces. Electromagnetic waves near the Upper Hybrid Resonance (UHR) frequency are occasionally observed near steep density gradients when intense EPO or UHR emissions are present. The onset or cessation of Auroral Kilometric Radiation (AKR) frequently coincides temporally with boundary crossings in the tail. Some continuum storms occur at constant delay times from the onset of AKR. Intense Electron Cyclotron Harmonic (ECH) emissions (also called "Totem Pole" emissions) have been observed coincident with the onset of moderately intense AKR and interesting structured escaping continuum radiation. Often escaping continuum radiation

appears to be generated at various boundaries in the tail. Frequently Extremely Low Frequency (ELF) electromagnetic waves are observed with enhanced Broadband Electrostatic Noise (BEN). Yet at other times, the ELF waves and BEN are strongly anti-correlated.

Roger R. Anderson attended and presented an invited talk at SCOSTEP's Eighth International Symposium on Solar Terrestrial Physics Dedicated to Solar Terrestrial Energy Program (STEP) and held at Sendai International Center, Sendai, JAPAN, on June 5-10, 1994. The resulting paper will be included in the Journal of Geomagnetism and Geoelectricity issue resulting from this conference. The title, author and co-authors, and abstract are:

Plasma Wave Signatures of Interesting Transient Phenomena Deep in the Earth's Geomagnetic Tail From the GEOTAIL PWI Multi-Channel Analyzer

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D A Gurnett (Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242; 319-335-1697; NSI IOWAVE::GURNETT)
W W L Taylor (Nichols Research Corporation, 1700 N Moore St., Suite 1820, Arlington, VA 22209; 703-527-2410; NSI NHQVAX::WTAYLOR)
H Matsumoto (Radio Atmospheric Science Center, Kyoto University, Uji, Kyoto 611, JAPAN; (81)774-33-2532; matsumot@kurasc.kyoto-u.ac.jp)
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Every pass that GEOTAIL makes into the Earth's deep geomagnetic tail (with apogee distances ranging from 60 Re to 220 Re) continues to yield very interesting plasma wave phenomena detected by the high-time-resolution PWI Multi-Channel Analyzer. Strong Electron Plasma Oscillations (EPO) have been observed simultaneously with low-frequency electromagnetic waves at Plasma Sheet Boundary Layer - Lobe interfaces. Electromagnetic waves near the Upper Hybrid Resonance (UHR) frequency are occasionally observed near steep density gradients when intense EPO or UHR emissions are present. The onset or cessation of Auroral Kilometric Radiation (AKR) frequently coincides temporally with boundary crossings in the tail. Isolated bursts of terrestrial myriametric (continuum) radiation in a limited frequency range from about 10 kHz to 50 kHz and lasting from tens of minutes to a few hours which we call "Continuum Storms" have been observed a few times per month throughout the tail. Some continuum storms occur at constant delay times from the

onset of AKR. Intense Electron Cyclotron Harmonic (ECH) emissions have been observed coincident with moderately intense AKR and structured escaping continuum radiation. Often escaping continuum radiation appears to be generated at various boundaries in the tail. Frequently Extremely Low Frequency (ELF) electromagnetic waves are observed with enhanced Broadband Electrostatic Noise (BEN). Yet at other times the ELF waves and BEN are strongly anti-correlated.

At the First International Workshop on Chaos and Non-linear Waves held at the Radio Atmospheric Science Center (RASC) of Kyoto University in Uji, Japan from June 13-16, 1994, Roger R. Anderson presented a talk "GEOTAIL Observations of Non-linear Plasma waves in Search of a Source". Following this meeting Dr. Anderson collaborated with his GEOTAIL colleagues at RASC and Kyoto University including Professors Hiroshi Matsumoto, Iwane Kimura, and Shinobu Machida and scientists Hiro Kojima and Yoshi Omura.

Before leaving Japan, Dr. Anderson travelled to the Institute of Space and Astronautical Science (ISAS) in Tokyo and collaborated with Professor Toshifumo Mukai and Tats Yamamoto from the GEOTAIL Low Energy Particle (LEP) and Magnetic Field (MGF) experiments.

Roger R. Anderson attended and presented papers at the 30th COSPAR Meeting in Hamburg, Germany, July 11-21, 1994. For the Meeting/Symposium D3.1, The Three-Dimensional Magnetosphere, the title, author and co-authors, and abstract of the contributed paper were:

<u>Geotail Plasma Wave Experiment Multi-Channel Analyzer Observations of Magnetospheric Structure and Dynamics</u>

R. R. Anderson and D. A. Gurnett (The University of Iowa, Department of Physics and Astronomy, Iowa City, Iowa 52242, USA)
W. W. L. Taylor (Nichols Research Corporation, 1700 N Moore St., Suite 1820, Arlington, VA 22209 USA)
H. Matsumoto and H. Kojima (Radio Atmospheric Science Center, Kyoto University, Uji, Kyoto 611, JAPAN)
I. Nagano (Dept of Electrical Engineering, Faculty of Technology, Kanazawa University, 2-40-20, Kodatsuno, Kanazawa 920, JAPAN)
S. Kokubun (STE Lab, Nagoya University, Toyokawa 442, JAPAN)
T. Yamamoto (Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara 229, JAPAN)
M. H. Acuna, D. H. Fairfield, and R. P. Lepping (NASA/Goddard Space Flight Center, Greenbelt, MD 20771 USA)

Since launch on July 24, 1992, GEOTAIL has traversed the Earth's geomagnetic tail more than a dozen times with apogee distances ranging from about 60 Re to more

than 220 Re. The perigee portion of several orbits have "skimmed" the magnetopause allowing several hours of continuous measurements within the magnetosheath or near the magnetopause or bow shock boundaries for each orbit. Complete plasma wave spectra from 5 Hz to 10 kHz (Magnetic) and 311 kHz (Electric) have been obtained every 1/4 or 1/2 second for a variety of magnetic field orientations. In the tail we observe continuum storms, intense Langmuir waves especially near steep density gradients, onsets of Auroral Kilometric Radiation, Broadband Electrostatic Noise, very-low-frequency whistler-mode noise, Type III Solar Radio Bursts, and other plasma wave phenomena whose occurrences may be related to substorm activity, boundary crossings, or other dynamical changes in the magnetosphere like plasmoids and flux transfer events.

The following paper was published in Journal of Geomagnetism and Geoelectricity, Vol. 46, pp 59-95, 1994.

Plasma Wave Observations with GEOTAIL Spacecraft

H. Matsumoto[1], I. Nagano[2], R. R. Anderson[3], H. Kojima[1], K. Hashimoto[4], M. Tsutsui[5], T. Okada[6], I. Kimura[7], Y. Omura[1], M. Okada[1]
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The main scientific objectives of GEOTAIL Plasma Wave Instrument (PWI) are to investigate the characteristic features of wave phenomena which are generated by a variety of plasma processes occurring within the Earth's magnetosphere.

The PWI measures plasma waves in the frequency range from 5.62 Hz to 800 kHz for the electric components and from 5.62 Hz to 12.5 kHz for the magnetic components. The instrument is composed of three distinct sets of receivers: (1) the Sweep Frequency Analyzer (SFA), (2) the Multi-Channel Analyzer (MCA) and (3) the Wave-Form Capture (WFC). The first two receivers are dedicated to wave spectra measurement, while the last one is used to capture actual waveforms of two electric and three magnetic field components for the measured plasma wave emissions.

The present paper describes the PWI subsystems and their functions. We also report some results from initial observations made during the traversal of the geomagnetic tail and a skimming pass of the dayside magnetopause. These observational results are useful in providing a good overview of the PWI capabilities as well as elucidating the characteristic features of the wave spectra in these regions.

Dr. William Taylor provided the following progress report in February 1994 for his work supported by a subcontract from The University of Iowa to Nichols Research Corporation:

"GEOTAIL Progress Report
W. Taylor/NRC
February 3, 1994

NRC has begun two research projects with The University of Iowa (U of I) Multichannel Analyzer (MCA),

1. A study of the plasma waves and wave/particle (plasma instrument data required) interactions in the transition region between volume that are in the plasma shadow of the moon and those that are unperturbed by the moon.
2. A study to determine the spectral distribution of plasma waves in the deep tail (beyond lunar orbit).

For the first study, eight periods of interest have been identified and the relative positions of the moon and GEOTAIL have been determined. MCA data has been examined for the first six time periods, and no unusual plasma wave phenomena have been noted. Particle and magnetic field data have been requested through The University of Iowa and Kyoto University.

For the second study, the time period of November and December 1993 has been chosen. 24 hour plots of the MCA data have been transferred from the U of I, in GIF (Graphic Interchange Format) to NRC, archived and printed. The next steps are to examine the 24 hour plots in detail and to do the spectral distribution statistics. The U of I has begun the process to determine the statistics."

In August, Dr. Taylor provided the following status report on his work on the Moon-GEOTAIL interaction:

"Roger,

This is an informal report to you on what I've concluded so far on the GEOTAIL encounters with the moon. I'll call later, after you have had a chance to read it, so we can discuss it and decide how to proceed.

I have examined the MCA data for all the encounter periods and have found nothing that appears unusual to me. I believe you have looked at the time periods as well and have found nothing that stands out. My next step is to look at particular time periods within the prime 4 hour periods for the encounters. Frank's initial e-mail response to my data request was that, of the encounters, only during the one on 11/8/92 (92-313) was the plasma flowing towards the Earth, that is, from the general direction of the moon towards GEOTAIL. GEOTAIL may have been in the solar wind or the magnetosheath during the other encounters. Based on that response, I have concentrated recently on the 11/8/92 time period from 04-08 hours UT.

The MGF data that you got from Kokubun for the study shows the magnetic field direction in theta and phi coordinates. During the four hour period, theta varies over its whole range, from -90 to +90 degrees, but with a two hour period from 05-07 hours when the variation is within the range of 0 to +30. Phi also varies over its whole range, from 0-360 degrees, during the four hours. With the exception of about 10 minutes at 05 hours, 40 minutes, phi is within the range of 150 to 210 for the same 05-07 hours period. So the 05-07 hours time period seems that it would be a likely time for interaction effects. The variation of the field direction, however, even during 05-07 hours, is much larger than the lunar diameter (about 10 degrees), as seen from GEOTAIL.

I have received orbital locations for GEOTAIL and the moon from the Satellite Situation Center at NSSDC and have derived and made plots of the separation angles, for the 11/8/92 encounter, to compare with the magnetic field direction. Surprisingly, during the four hours, there are only two times when the magnetic field and separation directions are within 5 degrees. Five degrees was chosen as the criterion since the angular radius of the moon as seen from GEOTAIL, is varies between 4 and 5 degrees during the 4 hours period.

The two time times are 05 hours, 11 minutes and 7 hours, 51 minutes (+or- about 2 minutes). I have looked at the MCA one hour plots for those times and see nothing unusual. I would appreciate it if you would also look at the data at those times, with your practiced eye, to see if it appears that there might be an effect.

I plan to plot the MGF data for the whole day and compare magnetic field and separation directions, so I may find some other likely times, although the 4 hour time period was the most likely period.

So far, I have seen no evidence of the Moon-GEOTAIL interaction.
Bill"

Although the initial results of this study are disappointing, we will continue to examine the plasma wave and other GEOTAIL plasma and field data for the additional lunar encounters that have occurred. In the meantime we are working on the deep-tail statistical programming on cooperation with Dr. Taylor.

The primary emphasis for the next year here at The University of Iowa will be to produce papers on the subjects discussed in the talks referred to throughout this report and to continue to study the newly acquired GEOTAIL data for other highlights. All GEOTAIL scientists had an agreement to refrain from publishing any GEOTAIL papers (other than the JGG Instrumentation papers) until the initial Geophysical Review Letters (GRL) papers were completed. Now that the GRL papers have all been submitted, we are free to publish within the bounds of the GEOTAIL Rules of the Road.

Respectfully Submitted,

Roger R Anderson

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