A History of the DE -1 Plasma Wave Investigation

This history summarizes the in-orbit operations, data reception and submission, data archiving, and scientific results related to the University of Iowa DynamicsExplorer (DE) Plasma Wave Investigation for the time period the instrument was operated; September 1983 through June 1994.

The University of Iowa Plasma Wave Instrument (PWI) was built by the Department of Physics and Astronomy under the direction of Professor Stanley D. Shawhan, Principal Investigator, under a NASA Contract awarded October 1977 through September 1981. A second NASA Contract provided support for pre-launch programming, in-flight operations, and data reduction and analysis from March 1980 through July1983. Professor Shawhan moved to NASA Headquarters and Professor Donald A. Gurnett was named to succeed him as Principal Investigator in September 1984.

The Plasma Wave Instrument on the Dynamics Explorer-1 spacecraft was designed to provide measurements of the electric and magnetic components of plasma waves in the Earth's magnetosphere. Five antennas were used for performing the plasma wave measurements: a 200-m tip-to-tip electric dipole antenna perpendicular to the spacecraft spin axis; a 9-m tip-to-tip electric dipole antenna parallel to the spacecraft spin axis; a 0.6-m short electric antenna oriented to measure electric fields parallel to the long wire antenna; a search coil magnetometer parallel to the spin axis; and a loop antenna perpendicular to the spin axis.

Signals from these antennas were processed by four receiver systems. When connected to the electric sensors, the Low Frequency Correlator and the Step Frequency Correlator together provided amplitude and phase measurements of electric and magnetic fields over a frequency range of 1 Hz to 410 kHz every 32 seconds. This frequency range includes most of the important characteristic frequencies of plasma encounter-ed along the orbit of this spacecraft. The wideband receiver was designed to transmit wideband waveform signals with bandwidths of 10 or 40 kHz from selected frequencies up to 2 MHz for high-resolution frequency time analysis. The Linear Wave Receiver measured plasma wave amplitudes in the frequency range of 1.5-16 kHz. A description of the PWI and the major subsystems is included in "The Plasma Wave and Quasi-Static Electric Field Instrument (PWI) for Dynamics Explorer-A" by Stanley D. Shawhan, Donald A. Gurnett, Daniel L. Odem, Robert A. Helliwell and Chung G. Park, Space Science Instrumentation, 5, 535, 1981.

The in-orbit operations, government furnished data, data reduction, archiving and data submission to NSSDC, and the scientific results related to the plasma wave experiments will be discussed in Sections I through VI

I. In-Orbit Operations

Efforts to obtain plasma wave data from the University of Iowa Plasma Wave Instrument on Dynamics Explorer-1 ceased on March 15, 1991, when spacecraft operations were terminated. Throughout the years of DE operations the PWI continued to acquire plasma wave measurements, although access to the entire spectrum of measurements was not consistently available. On June 23, 1984, a failure in the circuitry of the spacecraft data-handling system led to intermittent acquisition of high frequency data from the PWI after this date. From June 1984 until November 1989, the Sweep Frequency Correlator (SFC) was not functioning properly, although internal monitors indicated that the rest of the PWI data appeared to be satisfactory. For several brief periods in 1987, the SFC data were restored to the telemetry frame. In late 1989, the SFC operation returned to normal until mid-November of 1990 when difficulties in commanding the spacecraft were encountered due to temperature problems. Until March 15, 1991, the PWI provided three-component DC electric field measurements and digital amplitude and phase data from 1 Hz to 410 kHz. Additionally, the PWI analog wideband subsystem operated within specification throughout the DE mission. During periods of reduced frequency capability, PWI operations concentrated on observations of low frequency phenomena. When available, the SFC data were utilized to provide observations of high frequency phenomena as well. The instrument modes used provided digital electric and magnetic spectra from 1 Hz - 410 kHz.

High resolution wideband analog data with bandwidths of 10 kHz and 40 kHz were available throughout the DE mission.

II. Project Furnished Data

In the period from April 1984 through September 1991, we received DE PWI decommutated telemetry data and merged the data to create 275 high-density 9-track tapes. The data on these tapes covers the entire span of the DE mission although the coverage is sporadic, especially in the later years, and there are many data gaps. The method of acquiring the telemetry data through the DE project's Honeywell Sigma 9-based data processing and distribution system, was slow and unsatisfactory and resulted in an incomplete in-house database when operations on the Sigma 9 were terminated in 1990. Only 50% of the PWI data for the first three years of the DE mission resides on 9-track tapes.

During the ten years of the DE operation, Iowa received 6786 wideband analog tapes. The tapes contain more than 350,000 minutes of the original raw wideband data. The data were processed in our Spectral Processing Facility to create film spectra. These processed film spectra continue to be stored at the University of Iowa and no other copies of the full wideband data set exist.

As a separate effort, in order to create a more permanent wideband data archive, a small percentage of the DE wideband analog data was digitized in house, and prepared for eventual archiving at NSSDC.

III. Data Reduction

Routine PWI data products which currently reside in-house include two-hour electric and magnetic field spectrograms, wave polarization and Poynting flux spectrograms. and 80-minute plots showing the DC electric field components parallel and perpendicular to the Earth's magnetic field. Color slides of the first three data products and black-and-white plots of the DC electric field components have been created for the 1981 and 1982 PWI data. Approximately 50% of the 1983 and early 1984 PWI data has also been similarly processed.

At the completion of our archiving tasks, gif files were created for the color spectrograms of the first three data products. 100% of the PWI data from September 16, 1981 through June 23, 1984 now resides in the form of gif files on 4mm and 8mm DAT tapes. Software was developed to display the spectrograms on our SUN workstations and produce hard copy prints of the desired spectrograms. Routine PWI data processing has been terminated. Requests from other investigators for PWI data are now handled through NSSDC, where the archived telemetry data and the processing software now reside.

The last wideband analog tape was received at Iowa in May 1991. During the period of this grant, 6786 tapes containing DE PWI wideband analog data were received at Iowa and 70mm film spectra have been created from the processed data. Routine wideband analog data processing and the wideband database listing were completed in late 1991. Work continues on the digitizing and archiving of selected wideband data intervals under a separate grant to archive the PWI analog data.

IV. Low-Rate Data Submission to NSSDC

From 1989 - 1992, the DE investigative teams were required to prepare and submit their data to NSSDC for archiving on optical platters. For PWI, the data in question excludes the wideband data. In order to complete our archiving obligations, we received copies of 212 DE telemetry platters, as well as several platters containing the orbit and attitude data. We stripped the PWI data from these platters, re-formatted and merged the data with the corresponding orbit and attitude data and wrote the re-formatted data to the archival platters. Our archiving obligation included all of the PWI digital electric

and magnetic field spectrum measurements and the DC electric field data for the period of September 16, 1981 through June 23, 1984. We completed our NSSDC archiving tasks and submitted our final installment of the DE PWI data on optical platter on July 6, 1992, along with the required format documentation and software metadata files.

V. Scientific Results

The plasma wave research efforts supported by this grant have been very productive. During the years of this NASA grant, research efforts involving the plasma wave data from the PWI have provided basic new information on a wide variety of magnetospheric plasma wave phenomena. Sixty-seven scientific publications, reports, and theses involving the University of Iowa plasma wave data were prepared during this grant period and are listed in Section VII. Oral and poster presentations related to research performed under this grant are given in Section VIII. Highlights of the discoveries made and research undertaken during this grant period include:

- **$** Identification of left-hand-polarized AKR, usually at frequencies just below the frequencies of simultaneously occurring right-hand-polarized AKR
- **$** Comparison of the AKR wideband spectra, showing that the spectra of both AKR modes exhibit fine structure and have similar spectra characteristics
- **$** Identification of harmonic structure in the AKR spectrum showing a reversal in polarization, indicating that the second harmonic component, an L-O mode emission, is of natural origin
- **$** Use of the DE 1 auroral images and the two-dimensional direction-finding capability of DE 1 to deter-mine that the AKR source is located on magnetic field lines associated with discrete auroral arcs
- **$** Development of the radio lasing theory for the generation of auroral kilometric radiation
- **$** Identification of the upper frequency cutoff of the auroral hiss emissions as the electron plasma frequency
- **$** Determination of the radial dependence of the electron density profile at high altitudes in the polar region
- **$** Use of plasma wave cutoffs to confirm the existence of a plasma density cavity along auroral field lines above 2 R_E and the correlation of the cavity with the observation of upward directed ion beams and conics
- **$** Observation of the flaring of the auroral hiss funnel as the wave frequency approached the electron plasma frequency, determination of the auroral hiss source position at auroral altitudes of 0.7-0.9 R_E and the use of Poynting flux observations to confirm that the hiss emissions are propagating upward above this position
- **$** Correlation between the observance of upward-directed electron beams and the occurrence of funnel-shaped auroral hiss emissions, confirming the generation of the hiss emissions via Landau resonance with upward moving electrons
- **$** Investigation of the Landau damping of auroral hiss, indicating that the hiss is limited to longer wavelengths and greater energies equatorward of the auroral oval, explaining the one-sided auroral hiss funnels observed by DE
- **$** Observation of funnel-shaped auroral hiss and broadband electrostatic noise associated with the presence of transpolar arcs
- **$** Observation of broad bandwidth Z-mode radiation in the low density regions over the auroral zone and polar cap and the horizontal propagation of Z-mode emissions below the electron cyclotron frequency
- **$** Use of direction-finding studies to confirm that Z-mode radiation is generated over the auroral zone and may originate from auroral hiss via a coupling window near the electron plasma frequency
- **$** Evidence that the cyclotron maser emission theory is not consistent with the observed spectra of Z-mode emissions deep in the polar cap and evidence, using ray tracing techniques, that the Z-mode emissions originate at low altitudes near the plasma frequency inside the auroral cavity
- **$** Evidence for locating the source of the four auroral wave propagation modes near the poleward edge of the auroral plasma cavity, with AKR originating in the X mode and O mode near the electron cyclotron frequency and the whistler mode and the Z mode originating at frequencies well below the local cyclotron frequency on the same source field lines

- **$** Confirmation of two predictions of the linear conversion theory for the generation of terrestrial myriametric (continuum) radiation (TMR) by coupling from intense upper hybrid resonance emissions near the plasmapause: the verification of the equatorial beaming of the TMR in two meridional beams at equal angles with respect to the magnetic equator at the plasmapause; and the confirmation of the expected L-O mode polarization of the TMR
- **$** Observation of an absence of a minimum in the occurrence and intensity of terrestrial myriametric radiation (TMR) at the equator and the emergence of several TMR beams at distinct angles from a single source, indicating that the radio window theory for the generation of TMR is not sufficient to explain the beaming pattern
- **$** Observation of generation of O+ conic distribution by equatorially confined ion cyclotron waves
- **$** Observation of hydrogen ion cyclotron harmonic bands up to the tenth harmonic within very low frequency (VLF) saucers in the auroral zone
- **$** Observation of double-peaked electrostatic H+ cyclotron harmonic waves below the lower hybrid frequency in the auroral zone, an uncharacteristic signature produced by Doppler shifts arising from a the satellite velocity relative to the plasma rest frame
- **$** Demonstration of a close correspondence between a strongly heated equatorially trapped H+ plasma population and the occurrence of ion Bernstein waves
- **$** Investigation of a magnetic structure at the equatorward edge of the polar cusp, consistent with an interpretation of a standing Alfven wave
- **$** Analysis of electrostatic auroral emissions as electron acoustic mode waves excited by field-aligned electron beams
- **$** Observation of wave intensifications near the electron cyclotron frequency within the polar cusp and the correlation of these enhancements in the narrowband electrostatic wave spectra with the velocity distribution of the energetic cusp electrons
- **$** Generation of broadband electrostatic bursts in the auroral zone by accelerated ions and electrons in the upward field-aligned current region and in the return current region
- **$** Use of correlator measurements to show that the north-south electric field fluctuations of the broadband low frequency auroral zone noise are closely correlated with the east-west magnetic field fluctuations and that the Poynting flux (electromagnetic energy flow) is directed downward, with an associated energy flow of approximately 10^8 watts
- **$** Correlation between the onset of low frequency waves in the cusp/cleft region and the onset of O+ heating and the development of a Monte Carlo simulation to explain the ion heating via a cyclotron resonance with broadband low frequency waves near the ion gyrofrequency
- **$** Theory for oxygen ion conic formation through cyclotron resonance with low-frequency magnetospheric plasma turbulence
- **$** Analysis of an O+ ion conic distribution in terms of ion acceleration along auroral field lines by the broadband low frequency electric field noise
- **$** Observation of the heating of oxygen ions equatorward of the central cusp/cleft region and the development of a resonant heating theory using heating rates inferred from the observed low-frequency electric field spectra on time scales consistent with the measured poleward drift rate of the thermal oxygen ions
- **$** Observation of funnel-shaped low frequency equatorial waves, consistent with generation by protons with a ring-type velocity space distribution
- **$** Demonstration, using magnetic conjunction techniques with DE 1 and DE 2 dc electric field data, that long-wavelength electric fields map from high to low altitudes with little or no attenuation and that short-wavelength fields are strongly attenuated, providing evidence for a magnetic field-aligned potential drop between the two satellites
- **$** Examination of the current-voltage relationship within narrow auroral current sheets using dc electric field data, revealing an "Ohm's law" relationship between the current density and the parallel potential drop along the magnetic field line
- **$** Statistical investigation of large-amplitude auroral electric fields, which are found to exhibit a strong radial dependence with the largest amplitudes found below 2.5 R_E,.