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Abstract

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FINAL TECHNICAL REPORT

ONR Contract N00014-81-K-0018

Paul M. Kintner, Principal Investigator

Michael C. Kelley, Co-Investigator

Denise Clark, Grant and Contract Officer

FINAL TECHNICAL REPORT

for

ONR Contract N00014-81-K-0018

I. Summary of Progress

This is the final technical report for ONR Contract N00014-81-K-0018. It contains a summary of published work from 1986 to the present and a summary of invited and contributed papers since 1986. In addition there is a more detailed technical discussion of progress made in space physics since 1986. Contributions were made in three basic areas: high altitude (> 1000 km) space physics, low altitude (< 1000 km) space physics, and controlled experiments in space.

During the course of this grant there were 18 papers published in archived, peer reviewed journals. Two of these papers were major reviews. There were additionally five symposium papers published. A listing of papers published since 1986 is contained in Table 1. In Table 2 is a listing of invited talks (7) and contributed talks (3) given since 1986. In addition to these measures of progress, two students received their Ph.D.'s with research primarily funded by this grant. One of those students is now an ONR Fellow.

Our study of high altitude space physics was primarily accomplished using the Viking spacecraft. There were many discoveries made in this program. Progress funded by this contract include the discovery of wide spread regions of spatial irregularities at virtually every altitude and spatial region encountered by Viking and the discovery of double layers in the auroral acceleration zone.

At lower altitudes several important discoveries were made in the area of wave-particle interactions which accelerate ions. Electrostatic oxygen cyclotron waves were discovered in a region of transverse ion acceleration. In addition hydrogen Bernstein waves near the lower hybrid frequency were shown to be a common feature of the auroral zone near 1000 km altitude.

In the area of active or controlled experiments, this contract funded the definitive experimental and theoretical investigation of artificial ion beams in space. We also confirmed the SEEP spacecraft results by showing that NAA and NSS precipitate radiation belt electrons via a resonant interaction.

The remainder of this report discusses in detail the contributions listed above.

TABLE 1

Publications Since 1986 Acknowledging

ONR Contract N00014-81-K-0018

- Kintner, P.M., Experimental identification of electrostatic plasma waves within ion conic acceleration regions, in Ion Acceleration in the Magnetosphere and Ionosphere, Geophysical Monograph 38, AGU, 384, 1986.
- LaBelle, J., P.M. Kintner and M.C. Kelley, Interferometric phase velocity measurements in the auroral electrojet, Planet Space Sci., 34, 1285, 1986.
- Koskinen, H.E.J., P.M. Kintner, G. Holmgren, B. Holback, G. Gustafsson, M. Andre and R. Lundin, Observations of ion cyclotron harmonic waves by the VIKING satellite, Geophys. Res. Lett., 14, 459, 1987.
- Kintner, P.M., M.C. Kelley, G. Holmgren, H. Koskinen, G. Gustafsson and J. LaBelle, Detection of spatial density irregularities with the VIKING plasma wave interferometer, Geophys. Res. Lett., 14, 467, 1987.
- Holmgren, G., R. Bostrom, G. Gustafsson and P.M. Kintner, Small scale plasma density structures observed by the VIKING double probe instrument, Proc. 21s, ESLAB Symposium, Bolkesjø, Norway, ESA SP-275, 139, 1987.
- Bostrom, R., G. Gustafsson, B. Holback, G. Holmgren, H. Koskinen and P.M. Kintner, Characteristics of solitary waves and weak double layers in the magnetospheric plasma, Phys. Rev. Lett., 61, 82, 1988.
- Arnoldy, R.L. and P.M. Kintner, Rocket observations of the precipitation of electrons by ground transmitters, J. Geophys. Res., 94(A6), 6825, 1989.
- Kintner, P.M., A technique for fully specifying plasma waves, Proceedings of the 1 Yosemite Conference, Outstanding Problems in Solar System Plasma Physics Theory and Instrumentation, Yosemite National Park, Yosemite, CA, 1988.
- Holmgren, G. and P.M. Kintner, Experimental evidence of widespread regions of small scale plasma irregularities in the magnetosphere, J. Geophys. Res., 95, 6015, 1990.
- Scales, W.A. and P.M. Kintner, Artificial ion beam instabilities 1: Linear theory, J. Geophys. Res., 95, 10,623, 1990.
- Scales, W.A. and P.M. Kintner, Artificial ion beam instabilities 2: Simulations, J. Geophys. Res., 95, 10,643, 1990.

TABLE 2

Invited Papers Since 1986 Acknowledging

ONR Contract N00014-81-K-0018

Arnoldy, R. and P.M. Kintner, Rocket observations of the precipitation of electrons by ground VLF transmitters, Fall AGU meeting, 1988.

Gustafsson, G., R. Bostrom, B. Holback, G. Holmgren, H.E.J. Koskinen, P.M. Kintner, Low frequency wave measurements by the VIKING satellite, Fall AGU.

Kintner, P.M., G. Gustafsson, and H.E.J. Koskinen, Plasma wave observations by the VIKING plasma wave interferometer, Fall AGU meeting.

Kintner, P.M., A consideration of mechanisms and evidence for energetic ion acceleration in the ionosphere, Chapman Conference, 1986.

Kintner, P.M., A technique for fully specifying plasma waves, Yosemite Conference, 1986.

Kintner, P.M., A physical interpretation of spatial irregularities, Cambridge Workshop, 1988.

Koskinen, H.E.J., G. Gustafsson, G. Holmgren, B. Holback, P.M. Kintner, M. Andre and R. Lundin, Observations of electrostatic ion cyclotron and ion cyclotron harmonic waves by the VIKING satellite, Fall AGU meeting, 1986.

Contributed Papers Acknowledging ONR

Holmgren, G., R. Bostrom, G. Gustafsson and P.M. Kintner, Small scale plasma density structures observed by the VIKING Double Probe Instrument, Fall AGU meeting, 1987.

Kintner, P.M., R. Arnoldy, M. McCarthy, R. Holzworth, D. Massey, G. Parks and U. Inan, A sounding rocket investigation of lightning induced wave particle precipitation, Fall AGU meeting, 1987.

Rodriguez, J.V., U.S. Inan, W.C. Armstrong, C. Yang, A.J. Smith, R. Orville, M. McCarthy, R.H. Holzworth, R.L. Arnoldy, P.M. Kintner and T.J. Rosenberg, Burst particle precipitation and clustered radio atmospherics: An apparent cause and effect relationship, Fall AGU meeting, 1988.

II. Technical Discussion of Results Obtained Under ONR N00014-81-K-0018

A. VIKING - The First Satellite Plasma Wave Interferometer

The Swedish spacecraft VIKING, launched on 22 February 1986, carried the first plasma wave interferometer (PWI) as part of the VIKING plasma wave receiver. The Principal Investigator for the VIKING plasma wave receiver is Georg Gustafsson at the Uppsala Ionospheric Observatory in Sweden, and Paul Kintner and Mike Kelley at Cornell University are co-Investigators with special interest in the VIKING PWI. VIKING and the plasma wave receiver worked superbly, and Cornell already possesses more than 100 orbits of plasma wave data from VIKING. During the first year of VIKING operations, Paul Kintner was awarded a Senior Scientist Fellowship by the Swedish Space Science Board to participate in real time operations and deliver a set of lectures on plasma waves in space. We have already published four papers on VIKING results in Geophysical and Research Letters, one paper in Physical Review Letters, and one paper has been accepted by the Journal of Geophysical Research.

Plasma wave interferometry yields information about the wavelength and phase velocity of plasma waves. The interferometric technique was first developed for plasma waves in space by Cornell (Kintner et al., 1984). During the past eight years we launched interferometers on sounding rockets to test various configurations and sensors. The VIKING interferometer is an evolution of the development on sounding rockets.

The VIKING interferometer is composed of two Langmuir probes separated by 80 meters perpendicular to the spin axis. From each Langmuir probe a $\delta n/n$ broadband signal is formed and then telemetered to the ground over the frequency range .5 - 428 Hz. Signals from each Langmuir probe may then be compared to show either phase differences or time of flight.

Spatial Irregularities

The VIKING interferometer has already made two important discoveries: large regions of spatial irregularities and ion acoustic double layers. An example of the interferometer response to spatial irregularities is shown in Figure 1. This figure consists of four panels. Each panel is a .3 sec snapshot taken during one spin of the spacecraft, and each panel consists of two data streams: one for the $\delta n/n(1)$ sensor, and one for the $\delta n/n(2)$ sensor. The four panels are selected to represent times when the interferometer axis is parallel to the geomagnetic field (0°), then perpendicular (90°), then parallel (180°), and finally perpendicular (270°). Careful inspection reveals that when the axis is parallel to the geomagnetic field, the two $\delta n/n$ signals are exactly in phase. On the other hand, for perpendicular configuration, one of the two sensors leads the other by about 1.4×10^{-2} sec. Hence, the phase velocity of these structures is given by $80 \text{ m}/1.4 \times 10^{-2} \text{ sec}$, or 5.4 km/s. Since this is nearly equal to the spacecraft velocity perpendicular to the geomagnetic field, we interpret the Langmuir probe signal as Doppler shifted spatial irregularities which are not propagating in the ionospheric reference frame.

These Langmuir probe signals may be analyzed more vigorously by employing a cross spectrum. The cross spectrum is created from the Fourier transform of each sensor (S_1 and S_2) and is defined as

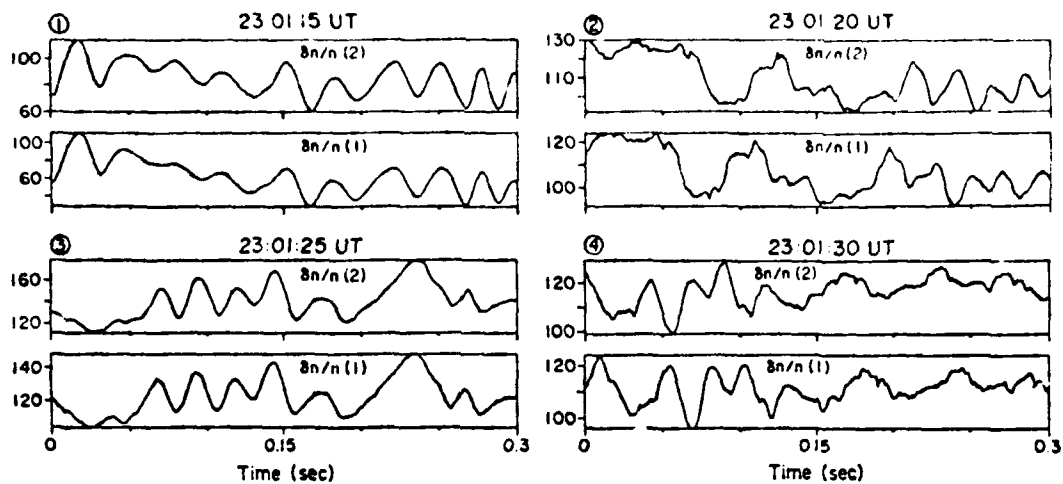


Figure 1. Waveforms from both $\delta n/n$ sensors at four points within a single spin. Panels 1, 2, 3, and 4 correspond to the angle between the interferometer axis and the magnetic field being 0° , 90° , 180° , and 270° respectively.

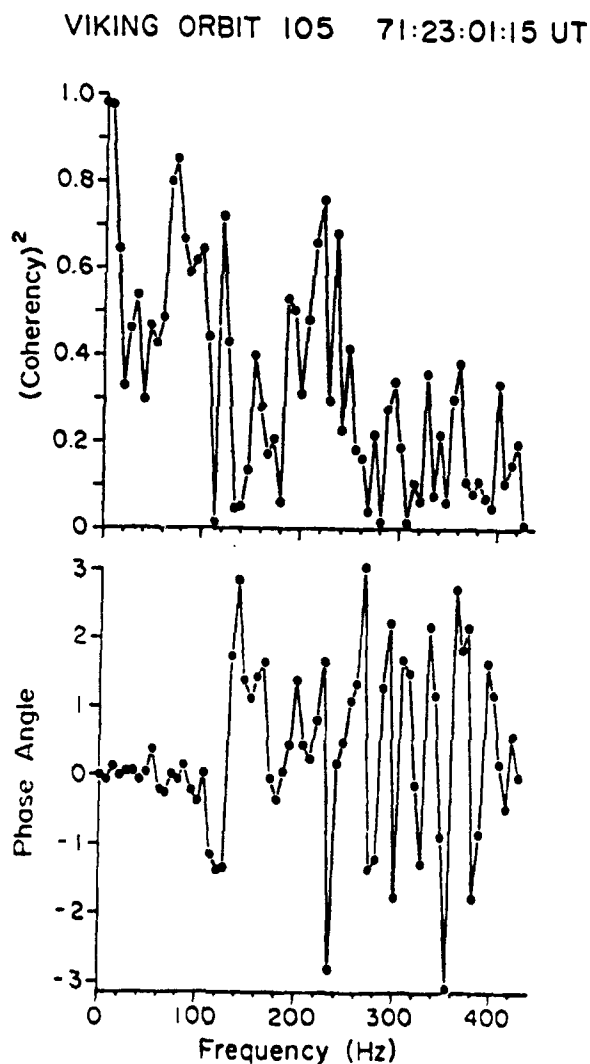


Figure 2. The cross spectrum of spatial irregularities when the angle between the interferometer axis and the magnetic field is 0° .

$$C_{12} = \frac{\langle S_1 S_2^* \rangle}{[\langle S_1^2 \rangle \langle S_2^2 \rangle]^{1/2}} = \gamma^2(\omega) e^{i\theta(\omega)}$$

The quantity γ is the coherency between the two signals while θ is the phase shift between the two signals. Both γ and θ are functions of frequency. For spatial irregularities, it is possible to show that the phase spectrum can be expressed as

$$\theta(\omega) = \frac{\omega d}{v} \sin\phi_2 \cos\phi_3 / \sin\phi_1$$

where d is the interferometer length, v is the spacecraft speed, ϕ_1 is the angle between the spacecraft velocity and the geomagnetic field, ϕ_2 is the angle between the interferometer axis and the geomagnetic field, and ϕ_3 is the angle between the projections of the interferometer axis and the spacecraft velocity onto the plane perpendicular to the geomagnetic field. Since ϕ_1 and ϕ_3 are roughly 90° , the dependence on spin phase is contained in ϕ_2 . When $\phi_2 = 0$ (parallel configuration), we expect $\theta(\omega) = 0$. On the other hand, when $\phi_2 = 90^\circ$, we expect $\theta(\omega) = A\omega$, where A is a constant. Figures 2 and 3 show the cross spectra of spatial turbulence for a parallel and perpendicular configuration. The parallel case in Figure 2 shows a region of enhanced coherency below 100 Hz, and the corresponding phase spectrum is $\theta = 0$ as expected. The perpendicular case in Figure 3 shows a region of enhanced coherency below 200 Hz, and the corresponding phase spectrum is a linear function of ω . By measuring the slope of the phase we deduced that the irregularity phase velocity was $5.1 \pm .3$ km/s compared to the spacecraft perpendicular velocity of 4.9 km/s.

The discovery of spatial density irregularities has two important consequences. First, it raises the issue of the origin of the irregularities and their significance to ionospheric physics as well as communications. Second, the irregularity phase velocities can be used to measure plasma drifts accurately. Since this kind of measurement is notoriously difficult to make with double probe electric field experiments, the interferometer promises to be a powerful new tool for sensing bulk plasma properties.

The cross spectral technique is a powerful tool enabling the development of two additional kinds of measurement. Since the cross spectral technique measures the velocity of spectral irregularities with respect to the spacecraft and since the spectral irregularities are to a good approximation fixed in the plasma, the cross spectrum yields one component of the spacecraft plasma velocity. For VIKING, that component corresponds to the quasi-static electric field that would normally be measured by the spin axis boom set. Since spin axis boom measurements are notoriously inaccurate, the cross spectral technique is a significant advance in electric field/plasma drift instrumentation.

The second kind of measurement enabled by the cross spectral technique is the automated detection of spatial irregularities through computer algorithms. Whenever the phase spectrum is a linear function of frequency, spatial irregularities are being detected. The coherency spectrum yields the per cent contribution that the spatial irregularities make to the power spectrum as a function of frequency. With this information we can automatically plot various parameters describing spatial irregularities such as broadband power and

VIKING ORBIT 105 71:23:01:20 UT

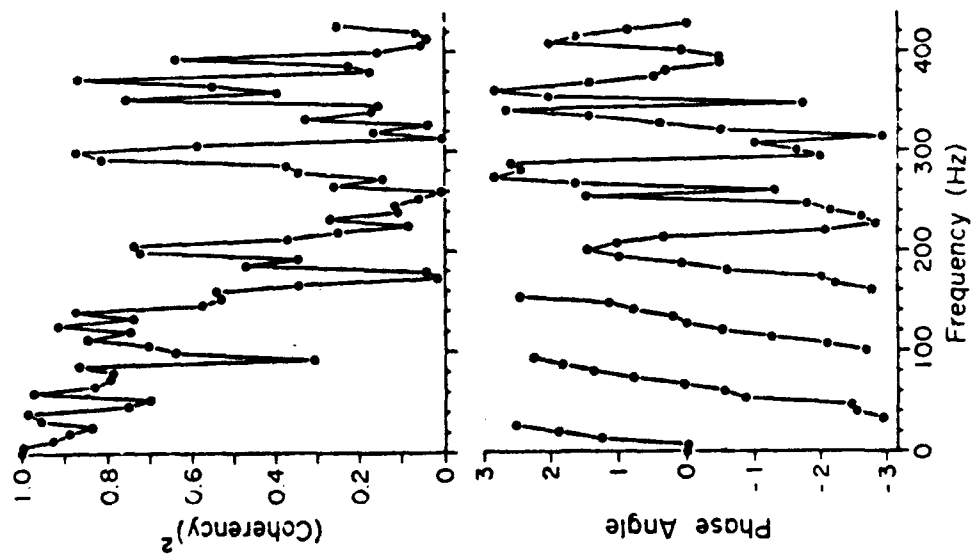


Figure 3. The cross spectrum of spatial irregularities when the angle between the interferometer axis and the magnetic field is 90° .

Viking $\delta n/n$ UIO

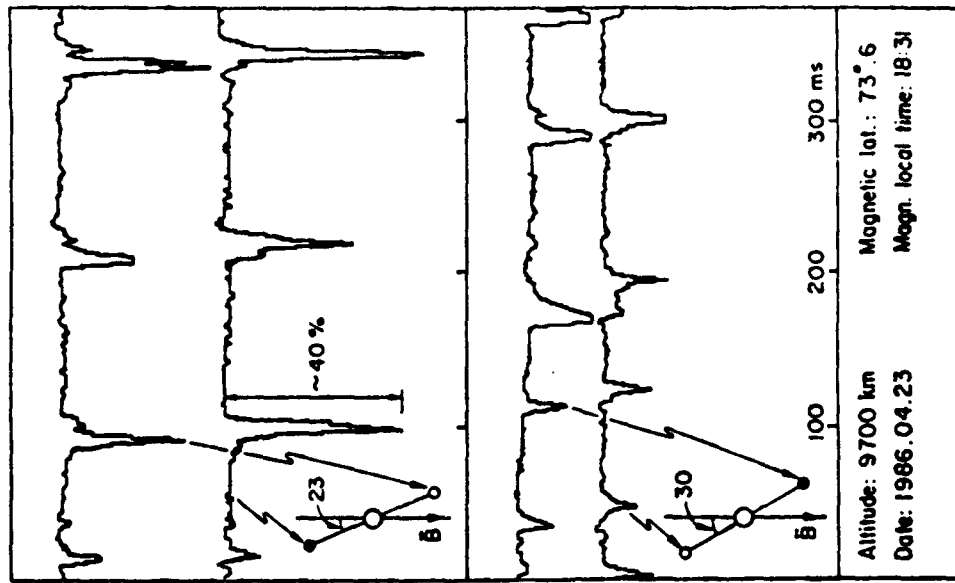


Figure 4. Observation of double layers by the $\delta n/n$ interferometer. The density cavities have up to 40% amplitude and propagate with speeds of 10-50 km/s.

spectral index. Before, these parameters could only be deduced by carefully examining small amounts of data at a single instant in time. This technique is opening up an entirely new way of examining spatial irregularities and plasma turbulence. We will continue analyzing VIKING data to develop a global picture of spectral irregularities; Freja will contain more advanced plasma wave interferometers to extend this technique even further.

Double Layers

Perhaps the most significant discovery by VIKING is the clear observation of ion acoustic double layers. For nearly three decades, space scientists have been searching for the mechanism which accelerates auroral electrons downward (and ions upward). The preliminary conclusion was that VIKING had discovered the primary mechanism, and after two years of study, the data still supports that conclusion. It appears that in regions of field-aligned current, many small (a few eV) potential steps develop in the form of double layers. These potential steps may be thought of as many small resistors strung along a magnetic field line. They resist the upward movement of ionospheric electrons but accelerate magnetospheric electrons downward to energies of many keV. VIKING unequivocally discovered these structures, and, if our preliminary conclusions are correct, has solved a fundamental and longstanding problem in space plasma physics.

Figure 4 shows an example of the double layers found in an upward ion beam. This figure shows the raw high frequency Langmuir probe response to the density field of the double layers. Each double layer appears as a 10% - 40% rarification structure lasting 10-15 msec. The two panels show the interferometer response for two difference orientations of the interferometer. In each case the lower probe responds first, implying that the double layers are propagating upward with velocities of the order 10-15 km/s. Closer examination of this data, along with electric field data, allows us to conclude that the structures have dimensions of about 100 m along the magnetic field, that the density structures are in Boltzman equilibrium with an electron gas of a few eV temperature, and that across each structure is a potential jump of a few eV. Assuming that the potential structures are distributed over a field line length of a few thousand kilometers, a total potential drop of a few keV can be easily produced. This is truly an exciting result.

The theory best supporting the VIKING double layer measurements has been articulated by Tetreault (1988) and co-workers. Their model arises from a combination of plausibility arguments, brief calculations, and intensive simulation. It is important to realize that a realistic description of double layers may not be tractable in the customary analytic sense. The basic model begins with a relative drift between the thermal electron and ion populations; a small hole develops in both ion configuration space and ion velocity space. The velocity space hole begins at a velocity the order of the thermal velocity or somewhat higher. Since the holes are electron rich, electrons reflect from the holes. In velocity space the hole decelerates toward smaller velocities and by Liouville's theorem, the depth of the hole grows in configuration space. Since the upstream electrons are mostly being reflected backwards, the upstream region has an excess of electrons compared to the downstream region. Thus a net potential drop exists between the upstream and downstream region. If electrons possess enough initial energy to cross the electron rich double layer, they enter the

downstream region and are accelerated by the net potential drop. By passing through many double layers, the electrons can eventually gain auroral energies.

This model is the best explanation fitting the known facts. Nonetheless major gaps exist in the model and exist in the picture of double layers developed through satellite data. The three-dimensional properties are largely unmeasured and the germane double layer theories are one-dimensional. The issue of multi-double layers is largely untouched. The altitude range, lifetimes, and spatial extent have large uncertainties in their determination. Hence, we intend to continue studying the subject to develop a better experimental picture and better theoretical models. We will conduct experimentation with the Freja spacecraft and through our sounding rocket programs. As double layer theories become more sophisticated, we will also continue to analyze VIKING data to respond to theoretical advances.

B. Auroral Zone Electric Field and Plasma Waves

The two most strongly driven regions of plasma within the terrestrial magnetosphere are the auroral acceleration region and reconnection regions in the magnetic tail. Access to the former region is technically much easier and over the last decade and a half the auroral acceleration region has been probed with both satellite and sounding rockets. The results from S3-3, VIKING, and DE-A are well-established. Particle distribution functions and perpendicular electric field measurements clearly implied the existence of parallel electric fields. These three spacecraft primarily obtained data from several thousand kilometers altitude. We now wish to make the point that the auroral acceleration zone extends much lower than previously believed, to less than 1000 km altitude and perhaps to 600 km or 700 km altitude. Recent Cornell sounding rocket measurements have established the existence of very large electric fields, intense wave activity, and plasma acceleration at these altitudes. We now wish to review these measurements by way of demonstrating our recent progress and also to demonstrate that the Freja spacecraft is likely to encounter a region that is at least as interesting as that which VIKING encountered.

We have successfully launched two sounding rockets to 900-1000 km altitude in the auroral zone. The first payload was MARIE, and we were co-Investigators for the plasma wave experiment. The second payload was TOPAZ 2 (TOpside Probe of the Auroral Zone) for which we were the Principal Investigators. Since TOPAZ 2 had somewhat more good fortune in encountering the aurora, and was designed using the experience of MARIE, we will primarily discuss TOPAZ 2 in this section.

TOPAZ 2 was launched on January 19, 1988 to an altitude of 930 km during the break-up phase of an auroral substorm. The aurora preceded to the north, stopped, and waited for the payload to catch up about ten minutes later. As the payload passed through apogee, it intersected several auroral arcs and then on the downleg at 800 km altitude, it intersected another arc system. The quasi-static electric field is shown in Figure 5. Until 450 sec ($\approx$ 900 km altitude), the electric field was small (< 100 mV/m) and pointed mostly to the south. Between 400 sec and 500 sec, the electric field increased to about 300 mV/m and its direction changed to a northerly direction. During the 500 sec to 600 sec period, the electric field direction remained in a northerly direction, and the electric field amplitude varied between 50 mV/m and 400 mV/m with an average of roughly 200 mV/m. A

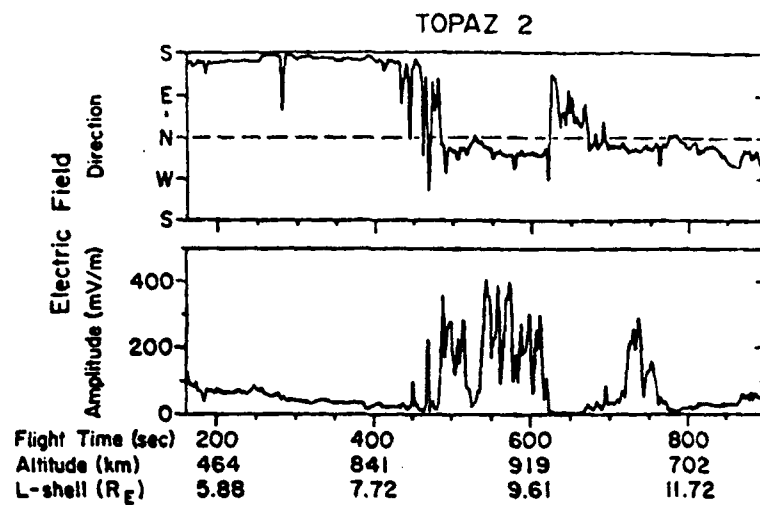


Figure 5. The direction and magnitude of the quasi-static electric field observed near 900 km altitude within active aurora.

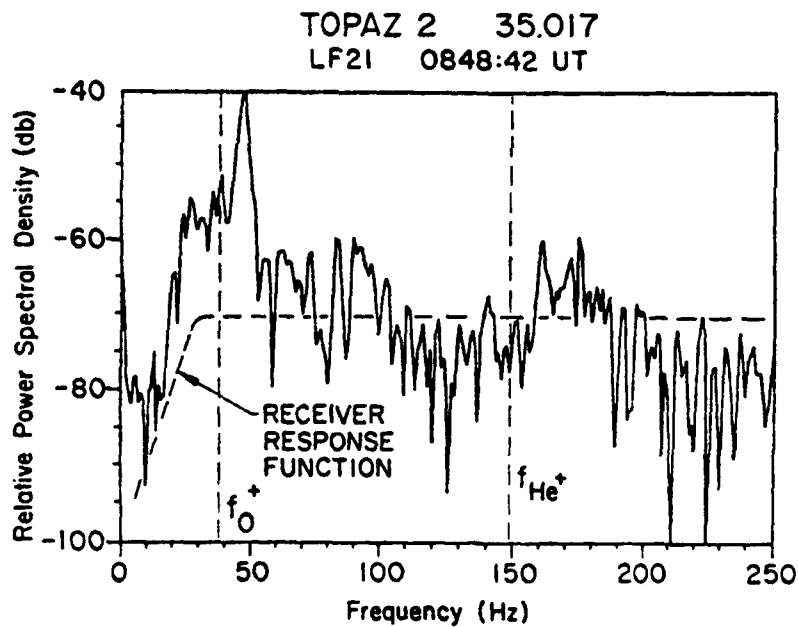


Figure 6. Power spectrum of electrostatic oxygen cyclotron waves.

second auroral arc was crossed between 700 sec and 750 sec when the electric field amplitude again rose to about 200 mV/m. This is an exceptionally large electric field with amplitudes comparable to the largest electric fields observed on S3-3 and VIKING. The reversal in electric field direction near 450 sec appears to be the plasma flow convection reversal commonly observed by high altitude polar orbiting spacecraft. Except for the fact that these observations were made near 900 km, they are strikingly similar to what Mozer called an "electrostatic shock" at higher altitudes.

Similar electric fields were also observed from the MARIE payload. The aurora were different in this case. Auroral arcs rapidly crossed the payload during two substorm expansion phases. The Cornell electric field instrument saturated at 225 mV/m and fields of 400 mV/m were likely. These fields were observed at lower altitudes (550 km to 700 km) and were observed for briefer periods of time (several ten-second bursts).

Together, these two sets of measurements imply that large, quasi-static electric fields penetrate much lower than previously believed. Since these large electric fields do not exist below 500 km, there must be parallel electric fields between 500 km and 1000 km. We will be investigating this hypothesis for the next several years within a variety of sounding rocket programs and Freja.

TOPAZ 2 also encountered a variety of plasma wave phenomena previously unreported. Since 1971 when Kindel and Kennel predicted the existence of electrostatic oxygen cyclotron (EOC) waves, several investigators have been vigorously looking for them. Electrostatic hydrogen cyclotron waves at higher altitudes were found in 1978 (Kintner et al., 1978) but only recently were the EOC waves discovered in the TOPAZ 2 data. Figure 6 shows a power spectrum of the EOC peak with the characteristic peak amplitude just above the oxygen cyclotron frequency which is diagnostic for this mode. Kintner et al. (1989) were additionally able to show that the waves were linearly polarized as expected and closely correlated with the observation of transversely accelerated ions (TAI).

Figure 7 shows in its top panel the maximum energy of TAI, or ion conics, when they were observed. The middle panel shows the quasi-static electric field in the sounding rocket reference frame with the large fields associated with the aurora near apogee. The lower panel shows the EOC electric field amplitude, which shows peak amplitudes of 5 mV/m (RMS) in association with the TAI and in association with the large quasi-static electric fields over apogee. The dramatic association of TAI with the EOC waves supports the theories of Palmadesso et al. (1974), Lysak et al. (1980), and Ashour-Abdalla and Okuda (1984), which use EOC waves to produce TAI. However, it is too early to reach this conclusion, and continued experiments are needed to understand this phenomena.

There is one additional observation made by MARIE and TOPAZ 2 which will likely be studied over the next five years using Freja: electrostatic hydrogen Bernstein waves (hB waves). These waves are observed above the lower hybrid frequency and are easily confused with the electromagnetic whistler mode, sometimes called auroral hiss. In fact, it appears that two decades of satellite measurements of auroral hiss have misinterpreted this phenomena. Figure 8 shows a power spectrum of hB waves between 2 kHz and 6 kHz. The vertical dashed lines are multiples of the hydrogen cyclotron frequency. The obvious structure, ordered by the hydrogen cyclotron frequency, is evidence of hB waves. This structure was clearly and continuously observed above 500 km altitude by

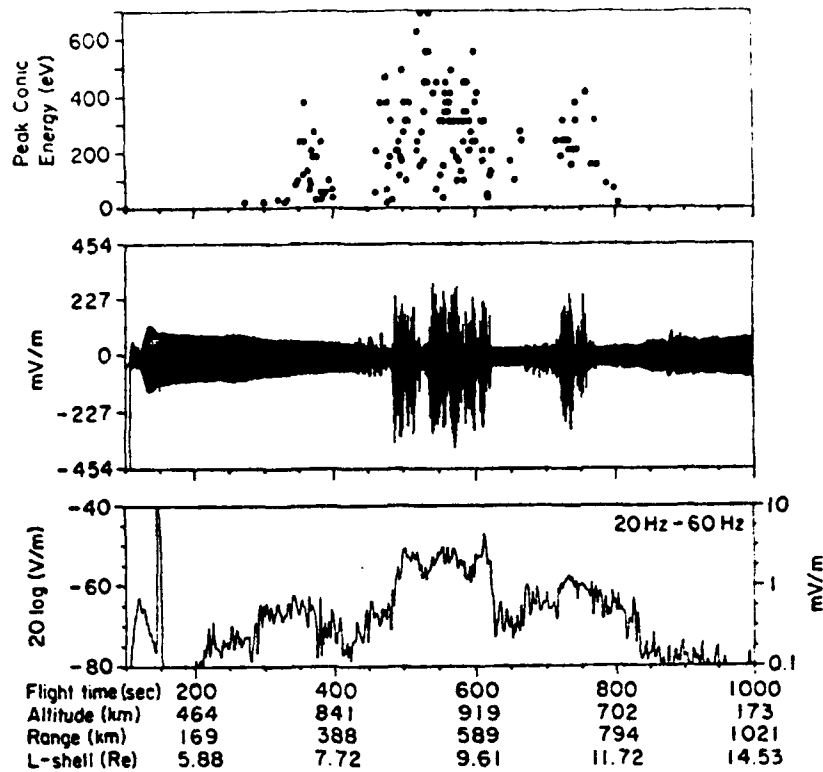


Figure 7. Top panel - maximum energy of observed conics when they were observed. Middle panel - quasi-static electric field in the payload reference frame. Bottom panel - EOC electric field amplitude.

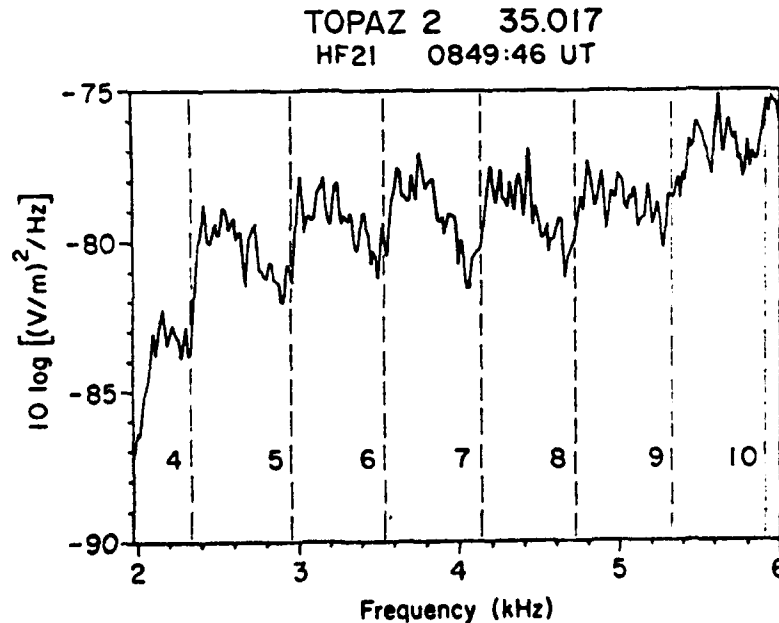


Figure 8. Hydrogen Bernstein waves ordered by the hydrogen cyclotron frequency.

both MARIE and TOPAZ 2. Additional interferometer measurements confirm the interpretation of hB waves. These observations support the theories of Chang and Coppi (1981), which use waves in this frequency and wavelength regime to produce TAI. These observations also cast doubt on the previous interpretations that whistler mode hiss is electromagnetic and long wavelength. A central goal of our research program will be to better understand this phenomena using sounding rockets and Freja.

C. Active Experiments

By active experiments, we mean those which inject chemicals, plasma, or waves into the ionosphere or magnetosphere. Although we have participated in roughly ten experiments releasing water, barium, or cesium, our principal focus has been on ion beam injection experiments, VLF wave-particle experiments with ground-based transmitters, and critical velocity experiments. We feel that these experiments have progressed as far as current technology will permit them, and in the future, we are planning different kinds of active experiments. Namely, we are planning to inject VLF waves directly from rocket- and satellite-borne transmitters, and we are planning to examine the ionospheric volume heated from Arecibo for evidence of Langmuir solitons. Later sections of this proposal will discuss these future plans. Next, we discuss our contributions to the physics of ion beam injections and VLF wave-particle interactions.

Our interest in ion beam injections began in the late 70's with the Porcupine program, and we continued this study with four more experiments named ARCS 1, 2, 3, and 4 (Argon Release Controlled Studies). The last experiment, ARCS 4, is scheduled for December 1990.

The Porcupine program consisted of four sounding rocket payloads, each of which contained an ejected subpayload with an Xe^+ ion beam. Cornell provided an electron density fluctuation probe ($\delta n/n$) on the main payload which observed intense plasma wave spectra with spectral peaks at multiples of the hydrogen gyrofrequency. An hypothesis was developed at Cornell to explain the generation of these waves which were eventually recognized as electrostatic hydrogen Bernstein waves (hB waves). Kintner and Kelley (1983) were able to explain hB waves using a model where an unmagnetized ion beam was injected into a magnetized ionospheric plasma with trace (1%) amounts of H^+ .

The ARCS 1, 2, and 3 series of experiments during the 80's followed the Porcupine experiments. Ar^+ beams were injected at a variety of angles, energies, and beam currents. The original Porcupine results were confirmed and greatly extended. A more rigorous theory to explain the generation of hB waves and other waves was developed by Wayne Scales as a graduate student at Cornell (Scales and Kintner, 1989a; Scales and Kintner, 1989b).

An important aspect of this work was the development of a model of electrostatic waves at VLF frequencies. Previously, VLF waves were believed to be electromagnetic whistler mode with possibly some quasi-electrostatic waves on the lower hybrid resonance cone. Now we are understanding that the original model was too simple. A more valid model, which is more complicated and in some ways more physically interesting, includes many electrostatic processes. For example, the previous section noted how naturally produced hB waves may produce TAI (ion conics). The ion beam injection experiments also produced hB waves and TAI. Figure 9 shows an example of ions observed during the ARCS 3

HIEPS ION MEASUREMENTS (2nd II Beam Event)

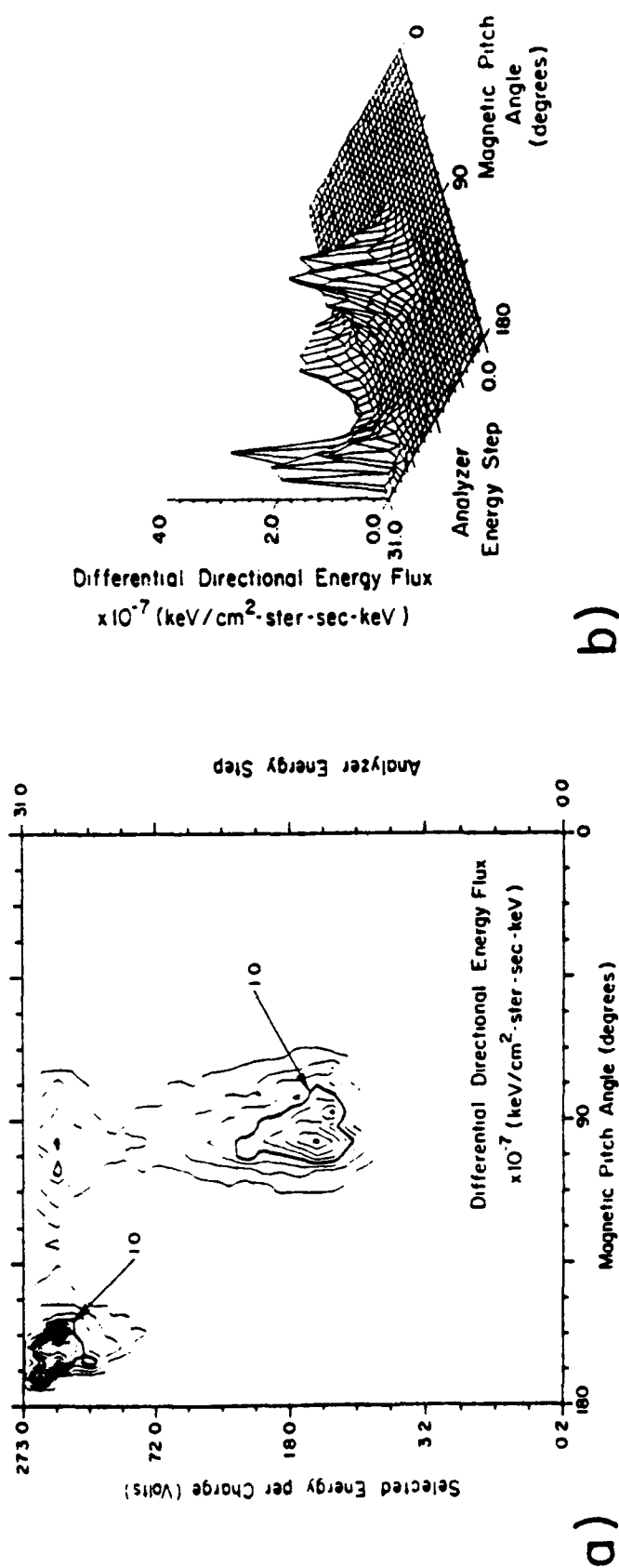


Figure 9. An example of transversely accelerated ions at roughly 10 eV energy and 90° pitch angle.

experiment. The ions at 150 - 200 eV were from the ion beam, while the ions at roughly 10 eV and 90° pitch angle were ions transversely accelerated from the ionospheric population. Scales and Kintner (1989b) demonstrate in a simulation that the injected ion beam produced the hB waves which in turn accelerates the ionospheric ions. To further develop our models we will be executing experiments which directly inject VLF waves.

The Cornell interest in VLF wave injection began with a series of three sounding rocket experiments at Siple Station, Antarctica in 1980-81. These payloads were launched over the Siple VLF antenna and directly observed the signal entry into the ionosphere as well as echoes from the opposite hemisphere (Kintner et al., 1983; Brittain et al., 1983). No precipitated particles were observed, probably because Siple is located near the South Atlantic anomaly. During the mid-80's, we developed inexpensive ground-based VLF receivers at Cornell for observing Trimpi events. The receivers were quite successful and were used for developing a data base which determined the launch window of the WIPP sounding rocket. The receivers were then used for making the launch decision. Further work with the Trimpi receivers was terminated since this technique was not shedding light on the physics of wave-particle interactions.

The WIPP sounding rocket, launched on July 31, 1989, was designed to detect electrons scattered by VLF waves over Wallops Flight Center (WFC). This location was chosen because the South Atlantic anomaly prevents electrons from being stable, trapped below 400 km altitudes. The payload was launched during a period of Trimpi activity between WFC and NSS in Cutler, Maine, and during an electron injection event at geostationary orbit. During the flight, the VLF wave receiver recorded whistlers and strong signals from the NSS and NAA transmitters. The particle detectors recorded two monoenergetic peaks in the electron spectrum roughly at 16 keV and 21 keV. The electron spectral peaks were shown to be produced by the NAA and NSS signals scattering marginally trapped electrons at the magnetic equator. No Trimpi events were observed during the flight.

We are planning no follow up flights to the WIPP experiment for two reasons. First, there is no reliable method of determining when to launch a sounding rocket. Second, the physics of the wave-particle interactions are occurring at the magnetic equator while the observations are near the bottom of the ionosphere. This arrangement makes a physical model difficult to develop.

Instead, we are planning to pursue a different technology to understand wave-particle interactions. We intend to transmit VLF waves from space-borne platforms. The first experiment is WISP 1, launched in February 1990. WISP 1 contains a 1 kw transmitter with a 60 meter electric dipole antenna. Cornell is responsible for the diagnostic subpayload. The second experiment is the Soviet ACTIVE satellite which was launched in 1989; it contains a 5 kw transmitter and a 30 meter magnetic loop. We are proposing as co-Investigators for this program. While we have no illusions concerning the fragile nature of this kind of collaboration, there is a potential to compare the WISP electric dipole technology with the ACTIVE magnetic loop technology. Finally, we have proposed for a WISP 2 payload in 1993.

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