GODDARD/GRANT

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Magnetospheric Studies Using the UKS Data

Grant No. NAG5-536

(NASA-CR-180273) MAGNETOSPHERIC STUDIES USING THE UKS DATA Semiannual Status Report, 15 May 1985 - 15 Nov. 1986 (California Univ.) 62 p CSCL 04A
N87-19822
Unclas
G3/46 43543

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March 31, 1987

Report for Period May 15, 1985 - November 15, 1986

Prepared for

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1. Introduction

This "semiannual report" covers the three reporting periods from the initiation of grant NAG5-536 in May 1985 to November 15, 1986. The purpose of the grant is to analyze the magnetic field data from the UKS spacecraft and hence learn more about the solar wind interaction with the earth's magnetosphere and about the magnetosphere itself. In order to undertake this task, we have to first reduce the data from essentially raw experimenter data records to engineering units. Then the data can be analyzed. The support for this effort to date has been minimal and the effort has proceeded much more slowly than would be optimum.

The UKS spacecraft was launched in August 1984 as part of the AMPTE mission. It co-orbits the earth with the IRM spacecraft in an orbit that reaches an apogee of close to 19 earth radii. The magnetometer is of a design identical to that of ISEE-1 and -2. The time resolution of the plasma data is an order of magnitude better than on ISEE-1 and -2. These improvements can lead to a better understanding of the bow shock, upstream waves, interplanetary shocks and the magnetopause. Furthermore, the existence of four spacecraft (the two ISEE's and the UKS-IRM pair) in the region of the solar wind interaction with the earth's magnetosphere permits a series of very critical correlative studies. We can examine the evolution of waves in the foreshock, the varying structure of the bow shock along the boundary, simultaneous behavior of the magnetopause in the north and south hemisphere and MHD waves in the magnetosphere and magnetosheath simultaneously.

History

UCLA refurbished, tested and calibrated its ISEE spare unit and delivered it to D. J.Southwood of Imperial College, London for installation on the UKS spacecraft. We also aided in the integration of the instrument on the spacecraft. We provided copies of our ISEE data reduction software to Imperial College as well as advice on instrument operations and data reduction. In 1985 we were provided initial copies of the telemetry data and requested money from NASA to enable us to reduce and analyze these data. We received only $30K, about one quarter of the requested amount of money. In 1986 we again requested support for this effort and again were awarded only $30K. This support is less than that provided guest investigators to study already reduced data. The fact that we also have to process the data in order to use it has impaired the amount of science we have been able to accomplish.

Data Reduction

In 1985 we attempted to process the preliminary experimenter data tapes. We were able to be successful on half of these tapes but were unsuccessful because of formatting errors and other undetermined errors on the data tapes. We could not afford to find the errors in these data sets and were unable to process half of the data.

In 1986 we received a new set of definitive data, this data is much improved but again we have run out of money before we could process all of it so that only half of the definitive tapes have been processed.

Team Support

During 1986 we supported the principal investigator D. J. Southwood by attendance at UKS team meetings twice and full AMPTE science meetings twice.

Software Development

Software was developed to process and display the AMPTE/UKS data based on the data reduction algorithms for the ISEE magnetometer. We have not been able to afford to write programs to display or list any orbit/attitude data.

Research Efforts

Upstream Waves. We have examined intervals of the joint occurrence of waves at ISEE and UKS in the foreshock region and found that the waves vary markedly with position. We have also found that the handedness of the waves vary with amplitude. These results have been presented at COSPAR and published in the COSPAR journal (Russell et al., 1986). A copy of this paper is attached. A more detailed examination of these waves was prepared and sent to JGR (Russell et al., 1987). It is now in press. A copy of this paper is attached.

We have begun a collaboration with Fred Scarf and Bob Strangeway on the CCE plasma wave observations of the bow shock on 1 November 1984. UKS was situated upstream of the bow shock, and can provide input parameters to determine the shock characteristics such as instantaneous θ_{Bn} and Mach number. Larry Zanetti at APL is also studying the CCE 1 November bow shock observations, and we are providing UKS upstream data as well as ISEE-1 solar wind and magnetosheath data from a somewhat different local time. This event promises to be well-supported observationally.

Magnetopause Studies

Another AMPTE/ISEE study begun 1986 centered on the nearly-simultaneous crossing of the dayside magnetopause at two widely separated sites on 19 September 1984. A preprint of a paper on this event is attached. The IMF was southward at this time and the spacecraft observed two important, related phenomena. First, between 1545 and 1600 UT, both UKS and ISEE observe a decrease in field strength, together with an inward tilting of the field at UKS (seen in the B_n component) north of the equator and an outward tilting at ISEE south of the equator. Second, flux transfer events (FTE's) are observed nearly simultaneously at the two widely separated sites. This paper is in preparation for JGR.

Another collaborative magnetopause study centers on 4 September 1984, when IRM and UKS pass through a highly compressed magnetopause. ISEE provided continuous upstream data during the event, and fortuitously, the SABRE radar in Britain was able to monitor ionospheric flows at the strongly displaced dayside auroral zone. During this event FTE's were observed at UKS and IRM, and ionospheric flow disturbances are observed by SABRE correlated with the FTE's

Other ISEE/AMPTE Studies

There are many other joint studies that can be undertaken with the ISEE and AMPTE data. Some of these are being actively pursued by the other groups and we will advise and assist as required. One such study begun in 1986 centers on an isolated plasma flow and field event observed by IRM on 28 March 1985 in the magnetotail. This IRM event coincides with disturbances observed in the ionosphere by EISCAT near the IRM footprint. Rick Elphic has been working with Wolfgang Baumjohann on the IRM plasma and field data, and has also supplied supporting ISEE data for several IRM/CCE magnetotail study intervals. The lack of resources prevent us from pursuing this as vigorously as we should.

Adv. Space Res. Vol. 6, No. 1, pp. 85–88, 1986
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0273–1177/86 $0.00 + .50

SIMULTANEOUS OBSERVATION OF UPSTREAM WAVES WITH ISEE AND AMPTE

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ABSTRACT

Measurements obtained by ISEE-2 and the UKS spacecraft upstream of the Earth's bow shock are examined. Simultaneous observations show that upstream waves are excited over a broad frequency range. Even when peaked spectra occur the peaks can occur at different frequencies in different regions of space. Generally the spectra seen at the two locations are most similar at high frequencies and least similar at low frequencies. The position dependent nature of the upstream waves indicates that comparisons between ground-based measurements and in situ observations must be undertaken with some caution.

INTRODUCTION

Energetic particles are observed to flow back toward the Sun on field lines that connect to the Earth's bow shock. Two mechanisms have been proposed for these returned beams. The first is leakage from the magnetosheath /1,2/. If the thermal speed of particles in the magnetosheath exceeds their drift speed, some of them can propagate back upstream. The second mechanism is reflection by the bow shock /3,4,5/. Energetic ions can have their motion reversed by the combined action of the magnetic gradient and the electric potential jump across the shock. Electrons have the greatest speeds and are observed first as one approaches the bow shock. Ions, moving more slowly upstream, are swept back somewhat by the interplanetary electric field. Thus, the ion foreshock boundary lags behind the electron foreshock boundary.

These energetic beams are accompanied by waves which grow on the free energy available in the beam-like particle distributions. Since the properties of the beams vary with position in the foreshock because of both source variations and propagation effects, and since waves have finite growth times we expect that the properties of the upstream waves should vary also. In fact, it has been known for some time that the properties of upstream MHD waves are quite position dependent /6/. However, our understanding of how the wave properties vary has been built up from many individual events under varied solar wind conditions. It is not always possible to ascertain what changes are due to the location of the observer and what are due to the different solar wind conditions.

The launch of the AMPTE mission in August 1984 with its two spacecraft that went into the solar wind, UKS and IRM, combined with the ISEE-1 and -2 spacecraft which had been launched in 1977, has allowed us to begin to probe spatial variations in the upstream waves under constant solar wind conditions. For this purpose we need study the data from only one spacecraft of each pair. We will choose to use the ISEE-2 /7/, and the UKS magnetometer data /8/ and solar wind data from the UKS three-dimensional ion instrument /9/.

OBSERVATIONS

We have reviewed all data obtained by ISEE-2 and the UKS while they were both returning data in the solar wind during October and November 1984. From these observations we selected for further study intervals during which one or both spacecraft were observing upstream waves and the interplanetary magnetic field was moderately steady. Below we illustrate the nature of the observations with four examples.

October 19, 1984. Figure 1 shows the simultaneous measurements obtained by ISEE-2 and UKS on day 293, 1984 from 0840 to 0848 UT. The right-hand two panels show the time series at one-second resolution. The top panel on the left shows the power spectrum summed over all three sensors. The bottom panel shows the location of the spacecraft relative to the foreshock boundary in the B-V plane. The B-V planes for the two spacecraft are parallel but displaced from each other. We have used the solar wind data supplied by M. Smith and A. Johnstone (personal communication, 1986) to scale the shock location.

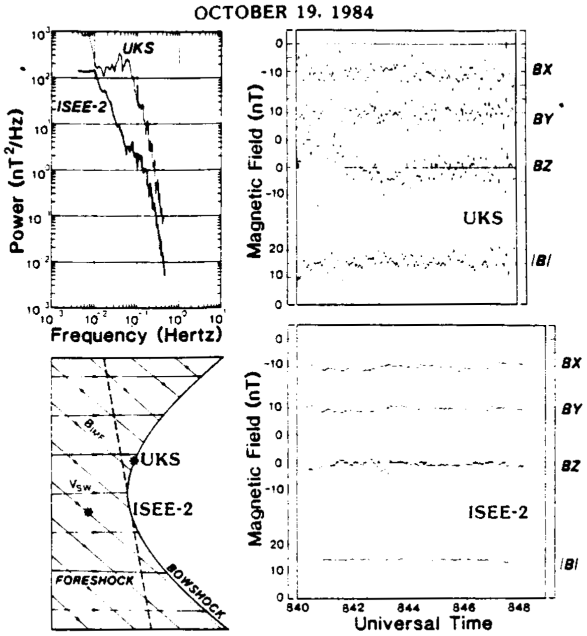

Fig. 1. The magnetic field power spectra, time series and foreshock geometry on October 19, 1984 at both ISEE-2 and UKS.

In this example ISEE-2 is outside the foreshock region and UKS is behind the foreshock boundary. The power spectrum at UKS is enhanced over that at ISEE over the entire spectral band from 200-seconds to 2-second periods. The waves at the peak of the spectrum at UKS are left-hand elliptically polarized, with an ellipticity of 0.73.

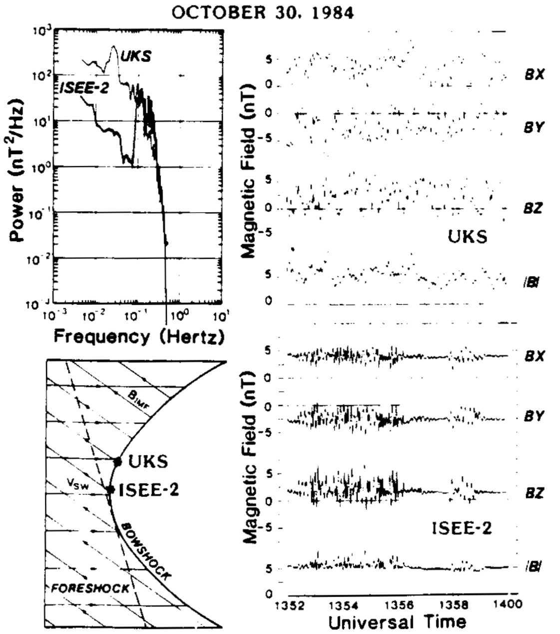

Fig. 2. The magnetic field power spectrum, time series and foreshock geometry on October 30, 1984.

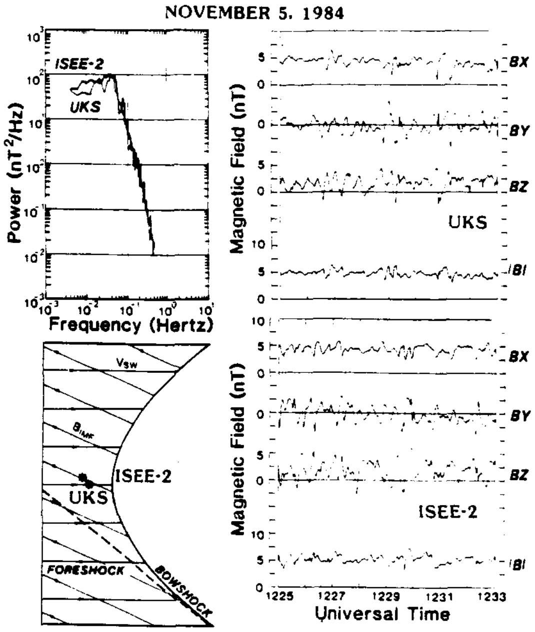

Fig. 3. The magnetic field power spectrum, time series and foreshock geometry on November 5, 1984 from 1225 to 1233 UT.

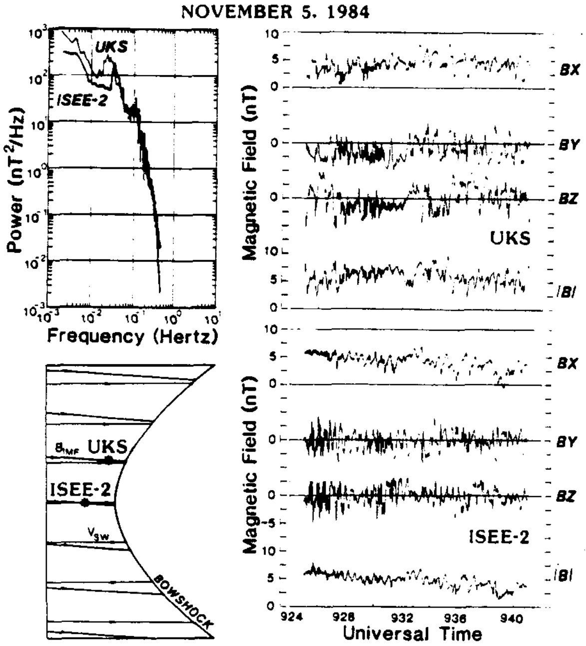

Fig. 4. The magnetic field power spectrum, time series and foreshock geometry on November 5, 1984 from 0925 to 0941 UT.

October 30, 1984. Figure 2 shows the observations on day 304, 1984 from 1352 to 1400 UT. ISEE and UKS lie close to the bow shock with ISEE close to the point of tangency of the foreshock with the bow shock. Here the power spectra at frequencies above 0.1 Hz are identical, but at low frequencies there is an almost complete absence of upstream waves at ISEE. It is possible that this difference is due to the presence of upstream electrons at ISEE but no upstream ions while at UKS both are present. The high frequency waves above 0.08 Hz are right-handed almost circularly polarized waves propagating at a small angle to the magnetic field. The low frequency waves peaking at about 0.025 Hz at UKS are also right-handed with an ellipticity of 0.34.

November 5, 1984(A). Figure 3 shows the observations on day 310 from 1225 to 1233 UT. At this time ISEE and UKS are nearly coincident in the B-V plane display but in fact are close to 10 Earth radii apart. The time series in the right-hand two panels and the power spectra show that the signals observed by the two spacecraft are quite similar. At both locations the signals are right-hand polarized with an ellipticity of about 0.6.

November 5, 1984(B). Figure 4 shows the observations three hours earlier on day 310 from 0925 to 0941 UT. Now the two spacecraft are well separated in the B-V plane. The spectra are qualitatively similar but they do differ at the lowest frequencies. In particular, they have different peak frequencies. Furthermore, the waves at ISEE are left-hand polarized while the waves at UKS are right-hand polarized.

DISCUSSION AND CONCLUSIONS

From our examination of those cases in which one spacecraft is in front of and the other spacecraft behind the foreshock as illustrated in Figure 1, it is clear that the enhancement in the power spectrum of upstream waves occurs across the entire frequency spectrum measured not just at around 0.03 Hz. This observation is important to those studying the source of Pc 3, 4 waves in the dayside magnetosphere. The upstream wave source has a broad spectrum. The narrow bandedness of the terrestrial emissions must have its source in the resonance of magnetospheric field lines.

Another observation of importance to those studying Pc 3, 4 waves is that spectral peaks may occur at different frequencies at different locations in the foreshock region. Thus, if one is conducting a correlative study between a ground observing site and a space observation and one observes a different frequency wave at the two locations, this does not imply that the ground-based signal does not have its origin in space. The signal observed on the ground might very well have propagated from some other region of the foreshock where the wave properties were different.

We note that the B-V coordinate system is a useful one for ordering the foreshock data. However, its success here should not be taken to imply that the wave properties depend only on the location of the spacecraft in this plane. In fact, when all observations of the upstream region are examined it becomes clear that the properties depend on the full three-dimensional geometry of the interaction.

ACKNOWLEDGMENTS

We wish to thank E. W. Greenstadt for the use of his program for displaying the B-V geometry of the bow shock and foreshock region and to M. A. Smith and A. Johnstone for the use of their data prior to publication. This work was supported by the National Aeronautics and Space Administration under research contracts NAG5-536 and NAS5-28448.

REFERENCES

1. D. A. Tidman and N. A. Krall, Shock Waves in Collisionless Plasmas, 175pp,

2. J. P. Edmiston, C. F. Kennel, and D. Eichler, Escape of heated ions upstream of quasi-parallel shocks, Geophys. Res. Lett., 9, 531, 1982.

3. B. U. O. Sonnerup, Acceleration of particles reflected at a shock front, J. Geophys. Res., 74, 1301, 1969.

4. G. Paschmann, N. Sckopke, J. R. Asbridge, S. J. Bame, and J. T. Gosling, Energization of solar wind ions by reflection from the earth's bow shock, J. Geophys. Res., 85, 4689, 1980.

5. S. J. Schwartz, M. F. Thomsen, and J. T. Gosling, Ions upstream of the earth's bow shock: A theoretical comparison of alternative source populations, J. Geophys. Res., 88, 2039, 1983.

6. C. T. Russell and M.M. Hoppe, Upstream waves and particles, Space Sci. Rev., 34, 155-172, 1983.

7. C. T. Russell, The ISEE-1 and -2 fluxgate magnetometers, IEEE Trans. Geosci. Elect., GE-16, 239-242, 1978.

8. D. J. Southwood, W. A. C. Mier-Jedrzejowicz, and C. T. Russell, The fluxgate magnetometer for the AMPTE UKS subsatellite, IEEE Trans. Geosci. Remote Sensing, GE-23, 301-304, 1985.

9. A. J. Coates, J. A. Bowles, R. A. Gowen, B. K. Hancock, A. D. Johnstone, and S. J. Kellock, AMPTE UKS three-dimensional ion experiment, IEEE Trans. Geosci. Remote Sensing, GE-23, 287-292, 1985.

Upstream Waves Simultaneously
Observed by ISEE and UKS

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Abstract

Measurements obtained in the solar wind by ISEE-2 and the United Kingdom Subsatellite UKS have been examined for observations of upstream waves. These data reveal that the waves in the foreshock region are enhanced at all frequencies from at least .003 Hz to 0.5 Hz. The wave spectra generally have a spectral peak but this peak is usually broad and the peak frequency depends on the position of the spacecraft. Generally the spectra seen at the two spacecraft are most similar at high frequencies and least similar at low frequencies. The geometry of the interaction is displayed in the plane containing the magnetic field and the solar wind velocity and the spacecraft location. However, this coordinate system does not order all the observed wave properties. It does not clearly explain or order the handedness of the waves, or their direction of propagation. It is clear that the upstream region is inherently three-dimensional. The position dependent nature of the upstream waves indicates that comparisons between ground-based measurements and in-situ observations must be undertaken with some caution.

Introduction

Our present understanding of the ULF waves observed upstream of the earth's bow shock is built upon many individual observations under varying solar wind conditions. From these individual observations we have developed a model of how the properties of the waves depend on the location of the observer relative to the magnetic field line tangent to the bow shock or more specifically a boundary somewhat behind the tangent field line known as the foreshock boundary. The variability of the solar wind properties from observation to observation limits our ability to determine precisely the spatial dependence of the properties of the waves. However, the launch of the AMPTE mission in August 1984 with its two spacecraft, IRM and UKS, in a highly elliptic orbit extending well into the solar wind, allows us to make observations of the upstream waves simultaneously with those obtained by the ISEE-1 and -2 spacecraft whose orbits also extend upstream of the shock. The apogee of the UKS and IRM spacecraft is at 18.7 earth radii (R_e). The apogee of the ISEE-1 and -2 spacecraft is 23 R_e.

The two spacecraft of each of these pairs are separated from each other by only a few hundred kilometers in the near apogee region. For the purpose of studying the spatial variations of the properties of the waves we need to examine only the data from one spacecraft of each pair. We will choose to use the ISEE-2 data and the UKS data, using the magnetic field data from the ISEE-2 fluxgate magnetometer (Russell, 1978) and from the UKS fluxgate magnetometer (Southwood et al., 1985) and the solar wind data from the UKS three-dimensional ion experiment (Coates et al., 1985). We note that the UKS fluxgate magnetometer was originally the spare unit for the ISEE-2 spacecraft and hence the two magnetometers are identical instruments. Any differences observed in the spectral properties of the waves observed with these instruments arise from the waves themselves.

Upstream waves have been studied for almost two decades beginning with Greenstadt et al. (1968) and Fairfield (1969). They have been found in front of the bow shocks of Mercury (Fairfield and Behannon, 1976), Venus and Jupiter (Hoppe and Russell, 1982) and interplanetary shocks (Russell et al., 1983). These upstream waves are clearly generated by MHD instabilities in the back-streaming particles that accompany these waves. These energetic particles can arise from either of two mechanisms. First, some fraction of the incoming ions may be reflected by the bow shock (Sonnerup, 1969; Paschmann et al., 1980; Schwartz et al., 1983). Second, ions heated by their passage through the bow shock may escape back upstream if their thermal energy is great enough (Tidman and Krall, 1971; Edmiston et al., 1982). It is probable that both these mechanisms are operative with varying relative strengths upstream of the bow shock, probably depending in part on the angle of the interplanetary magnetic field to the shock normal at the source of the upstreaming particles. Thus the properties of the beams should depend on location within the foreshock because of variations in the source of the beams. In addition, the beams should evolve with distance from the shock due to the presence of the MHD instabilities that generate the waves. As we will see below the properties of the waves are also quite spatially dependent.

Finally, we note that there is much evidence that the waves generated in the upstream region are convected through the bow shock and magnetosheath and couple into the magnetosphere exciting dayside Pc 3-4 magnetic pulsations. For a recent review of this topic the interested reader is referred to the paper by Odera (1986).

Observations

We have examined all the available UKS and ISEE-2 magnetic records in October and November 1984 while both spacecraft were returning measurements in the solar wind. From these data we have selected intervals of from 8 to 16 minutes long during which the interplanetary magnetic field was fairly steady in direction. During most the these intervals both ISEE and UKS were in the upstream wave region. We picked two periods with only one satellite in the upstream wave reigon to further illustrate the nature of the upstream waves.

October 19, 1984. Figure 1 shows the simultaneous measurements obtained by ISEE-2 and UKS on 10/19/84 (day 293) from 0840 to 0848 UT. On the right-hand side are the two time series at one-second resolution in solar ecliptic coordinates.

On the left-hand side in the top panel is the power spectrum of the waves summed over the three sensors. The bottom left-hand panel shows the geometry of the observations. The plane shown is the B-V plane containing the solar wind velocity, the interplanetary magnetic field direction and the spacecraft. The B-V planes for the two spacecraft differ but have been superimposed here under the assumption that the nature of the waves observed depends only on the relative location of the spacecraft in the B-V plane. The foreshock location has been sketched in under the assumption that the upstream beams have an energy of 1.2 times that of the incoming solar wind protons (Greenstadt and Baum, 1986). In order to scale the size of the bow shock we have used the solar wind parameters measured by the UKS three-dimensional plasma analyzer. These data, together with the location of the spacecraft and magnetic field direction in solar ecliptic coordinates are given in Table 1. The format of the following figures will resemble that of Figure 1.

In this example ISEE-2 is outside the foreshock region and UKS is within it. We see that the power spectrum at UKS is enhanced over that at ISEE over the entire spectral band from 200 second period to 2 second period. The waves at the peak of the spectrum seen at UKS are left-handed polarized, propagating at 23° to the magnetic field according to the spectral analysis technique of Means (1972). The waves are elliptically polarized with an ellipticity of 73%. The percent polarization is moderate, 58%.. These parameters are summarized in Table 2.

October 23, 1984. Figure 2 shows the simultaneous measurements obtained by ISEE-2 and UKS on 10/23/83 (day 297) from 0845 to 0853 UT in the same format as Figure 1. In this example the interplanetary magnetic field has rotated so that it is nearly orthogonal to the usual spiral angle. In this situation UKS is outside the foreshock and ISEE-2 is inside the foreshock. We note that the solar wind density of 7 cm^{-3} used in Table 2 and in constructing Figure 2 was assumed so that both spacecraft were in front of the bow shock in Figure 2. The ion instrument was not in the proper mode to return an accurate measure of the solar wind density at this time. In this example ISEE observes the upstream waves and UKS has a much reduced spectrum. Again we see an enhancement in the upstream waves region over the entire frequency spectrum. The waves at the peak of the spectral enhancement are right-handed here and not left-handed as in the previous example. The waves are propagating at a large angle to the magnetic field, 44°, and are only weakly polarized, 36%. There is a slight enhancement of the waves at high frequencies above 0.1 Hz. We believe this is due to natural emissions possibly associated with electrons returning along field lines which connect to the shock but upstream of the foreshock boundary (Feldman et al., 1983).

<u>October 30, 1984</u>. In this example, from 1352 to 1400 UT on day 304, 1984, ISEE and UKS both lie close to the bow shock but ISEE lies close to the point of tangency of the foreshock boundary with the bow shock. Figure 3 shows that at frequencies above 0.1 Hz both spectra are identical. Yet at low freqencies there is an almost complete absence of waves at ISEE. This phenomenon may be the same as discussed in the previous example. Upstream electrons might be generating waves at both ISEE and UKS but either the ions present at ISEE, and upstream of ISEE, had not had enough time to generate measureable waves or the bow shock was somewhat smaller than sketched and only electrons and not ions were present at ISEE. The waves at high frequencies, above .08 Hz are almost identical in all their properties. They are right-handed, almost circularly polarized waves, $\varepsilon \sim .91$, propagating at a small angle to the magnetic field, 18-20°, and highly polarized, 80-98%, as shown in

Table 2. The low frequency waves that peak at about .025 Hz at UKS are also right-hand polarized with an ellipticity of 0.34, are propagating at large angle to the magnetic field, 65°, and are moderately well polarized, 74%.

November 5A, 1984. As indicated in Table 1, from 1225 to 1233 on day 310 ISEE-1 and UKS lay about 12 R_e apart. Nevertheless, as shown in Figure 4, the two spacecraft lay very close as projected in the B-V plane. Examination of the wave forms on the right-hand side of Figure 4 show the time series to be quite different. However, their power spectral densities are similar. Their spectra almost lie on top of one another with UKS, which is slightly closer to the foreshock-bow shock tangency, being slightly below ISEE at the lowest frequencies. As shown in Table 2 the waves at the peak of the spectrum are right-handed ellipically polarized with ellipticities of about 0.6, propagating at moderate angles to the field, 14° and 37° and have weak percent polarizations, 21 and 57%. At frequencies near 0.1 Hz the waves have very similar amplitudes at the two spacecraft but are decidedly different in polarization. At AMPTE the waves are left handed polarized with an ellipticity of -0.35 but at ISEE they are right-hand polarized with a polarization of 0.89. At both locations the waves are propagating nearly along the field.

November 5B, 1984. Three hours earlier than the above event, the magnetic field orientation was sufficiently different that ISEE and UKS became well separated in the foreshock as shown in Figure 5. Now the spectra at the two locations are different but only at the lowest frequencies. Above .03 Hz the spectra are identical. The lower spectral densities are observed at ISEE which is further from the shock. The properties of the waves at the peaks of the two spectra are given in Table 2. The waves have a large angle of propagation to the field 36° and 59°, and are weakly polarized. The waves differ markedly in their polarizations. At ISEE they are left-hand polarized while at UKS they are right-hand polarized. This is true whether the entire bandwidths of the two peaks are analyzed or the exact same bands of frequencies are analyzed at the two spacecraft. At higher frequencies near 0.1 Hz, the waves become more circularly polarized, propagate more nearly along the field, are more highly polarized and are more similar in their properties than near the peak of the wave spectrum.

October 6, 1984. A similar geometrical situation is found on day 280 from 1228 to 1244 as shown in Figure 6. However, here ISEE-2 is closer to the bow shock. Again the spectra are nearly identical at high frequencies. The waves at the spectral peaks near .06 Hz are propagating at a small angle to the magnetic field, 9° at UKS and 19° at ISEE and are only weakly polarized at UKS, 32%, but more strongly polarized at ISEE, 76%. The waves are left-hand polarized at both locations with the ISEE waves being the more circularly polarized.

October 14, 1984. The major difference between this event from 0829-0840 on day 288 and the previous one is that ISEE-2 is further from the bow shock. The spectra now coincide only at the very highest frequencies. The waves at both locations are propagating at a large angle to the magnetic field, 53° at UKS and 80° at ISEE. The waves are right-handed at UKS with an ellipticity of 0.45 and are nearly linearly polarized at ISEE with an ellipticity of -0.16. At both locations the waves have moderate percent populations, 40% at UKS and 68% at ISEE. We note that in this example the B-V planes through the locations of the two spacecraft are very close, only 0.8 R_e apart.

October 29, 1984. This example from 1213 to 1229 UT on day 303, as shown in Figure 8, is not unlike the previous example. The principal difference is that the B-V planes through the two spacecraft here are 8.4 R_e apart. The waves at UKS are propagating much more closely to the field direction than at ISEE, 15° at UKS but 72° at ISEE. The waves at UKS are almost right-hand circularly polarized with an eccentricity of 0.77 and at ISEE are almost linearly polarized with an eccentricity of -.12. The UKS waves have a low, 20% percent polarization while the waves at ISEE have a moderate percent polarization of 58%.

October 27, 1984. On day 301 from 0722 to 0738 UT ISEE and UKS were again similarly situated but spread somewhat farther apart in the B-V plane as illustrated in Figure 9. The separation of the two B-V planes, however, was half that of Figure 8. Here the spectra are more closely aligned especially at the higher frequencies. At both locations we observe waves propagating nearly along the magnetic field with right-hand polarization.

November 26, 1984. In our last example from 0704 to 0712 on day 331 shown in Figure 10, ISEE was nearly radially upstream of UKS. Here the B-

V planes are almost coincident. The waves seen at UKS downstream from ISEE are much larger than those seen at ISEE. One possible explanation of this is that UKS is right at the bow shock and that the oscillations seen at UKS are in fact the pulsations associated with the quasi-parallel shock. The waves seen at ISEE are highly polarized with an 88% polarization, are left-handed with an ellipticity of -0.67 and are propagating at an angle of 31° to the magnetic field. The waves seen at UKS are also moderately polarized with a 68% polarization but are right-hand polarized with an ellipticity of 0.64. The UKS waves are propagating at an angle of only 12° to the magnetic field.

Discussion

The availability of simultaneous observations in two quite separate regions of the foreshock gives us very useful insight into the nature of the waves upstream of the bow shock. First, it is evident from our examination of those cases in which one spacecraft is beyond the foreshock boundary such as on October 19 and 23, that the enhancement in the power spectrum takes place at all frequencies, not just in the spectral band centered at around 0.03 Hz. This fact is important for those studying Pc3, 4 waves in the dayside magnetosphere. It seems not to be appreciated that the upstream wave spectrum is broad. If these waves are convected to the magnetopause and couple to the magnetosphere they can excite a wide range of frequencies in the magnetosphere. The narrow band emissions seen there must be a magnetospheric effect and not a reflection of a narrow band source.

There are certainly spectral peaks in the upstream waves. Almost every spectrum had a distinguishable spectral enhancement or peak. However, the peaks seen simultaneously at different spacecraft were not necessarily at the same frequency. The events of November 5 (Figure 5) and October 6 (Figure 6) clearly illustrate this difference. This position-dependent spectrum may explain why different ground observing sites have different responses to the interplanetary magnetic field. The variability of the dependence of the period of waves seen at various ground stations on the strength of the interplanetary magnetic field and the apparent differences between the dependence seen on the ground and at arbitrary locations in the foreshock led Green et al. (1983) to call into question whether upstream waves are a major source of magnetospheric Pc 3-4 pulsations. However, before these conclusions can be drawn one must compare ground data with the waves in space that will be convected to the magnetopause.

The B-V coordinate system used herein is a convenient system in which to visualize the spacecraft positions and it provides much order to the data. However, it does not order all the wave properties. We have examined the handedness of the waves, their angle of propagation to the magnetic field and their percent polarization as a function of position in the B-V plane and have found no ordering. Thus, we feel that waves properties are determined by the three-dimensional nature of the interaction. For example the B-V plane diagrams do not properly exhibit the angle between the IMF and the shock normal because the shock normal is not necessarily a vector in the B-V plane.

We have also looked for correlations between parameters. Specifically we examined the correlation between eccentricity and percent polarization and between angle of propagation and percent polarization and found no correlation. We did, however, find one correlation between eccentricity and the fractional amplitude of the waves, the square root of the power in the peak of the spectrum normalized by the background magnetic field strength. This correlation is shown in Figure 11. When the fractional amplitude is 0.3 or below the waves are left-handed in the spacecraft frame and when they are above 0.3 in amplitude the waves are right-handed in the spacecraft frame.

We emphasize that these left and right handed waves are not two separate populations occuring under different solar wind conditions but that both polarizations occur simultaneously in different regions of the foreshock. Examples of this simultaneous occurrences of the two polarizations are the waves illustrated in Figures 5, 7, 8, and 10. This observation is consistent with the analysis of Hoppe and Russell (1983) who showed that the narrow band waves were generally right-handed. We understand these differences in terms of both resonant and non-resonant instabilities as discussed by Sentman et al. (1981).

Conclusions

We have examined a number of examples of simultaneous magnetic field measurements in the upstream region ahead of the bow shock using the identical magnetometers flown on ISEE-2 and UKS. On field lines behind the ion foreshock boundary, waves appear over the entire frequency range from .003 to .5 hz. Their power spectra are generally peaked. However, the peak frequency is position dependent. Generally spectra are most similar at the two spacecraft at the higher frequencies. The B-V plane is useful for ordering the observations to first order but this coordinate system does not order all the wave properties such as percent polarization, handedness, or direction of propagation. Thus the upstream wave region is inherently three-dimensional. The positional dependence of the spectral peak of the upstream waves indicates that caution must be exercised when comparing simultaneous measurements on the ground and in space, or even comparing statistical properties, for only a fraction of the waves in the upstream region convect against the magnetopause.

Acknowledgements

We wish to thank E. W. Greenstadt fo the use of his program for displaying th B-V geometry of the bow shock and foreshock region. This work was supported by the National Aeronautics and Space Administration under contracts NAG5-536 and NAS5-28448.

References

Coates, A. J., J. A. Bowles, R. A. Gowen, B. K. Hancock, A. D. Johnstone and S. J. Kellock, AMPTE UKS three-dimensional ion experiment, IEEE Trans. Geosci. Remote Sensing, GE-23, 287-292, 1985.

Edmiston, J. P., C. F. Kennel and D. Eichler, Escape of heated ions upstream of quasi-parallel shocks, Geophys. Res. Lett., 9, 531, 1982,.

Fairfield, D. H., Bow shock associated waves observed in the far upstream interplanetary medium, J. Geophys. Res., 74, 3541, 1969.

Fairfield, D. H. and K. W. Behannon, Bow shock and magnetosheath waves at Mercury, J. Geophys. Res., 81, 3897, 1976.

Feldman, W. C., R. C. Anderson, S. J. Bame, S. P. Gary, J. T. Gosling, D. J. McComas, M. F. Thomsen, G. Paschmann and M. M. Hoppe, electron velocity distributions near the earth's bow shock, J. Geophys. Res., 88, 96-110, 1983.

Green, C. A., T. J. Odera and W. F. Stuart, The relationship between the strength of the IMF and the frequency of magnetic pulsations on the ground and in the solar wind, Planet. Space Sci., 31, 559-567, 1983.

Greenstadt, E. W., and L. W. Baum, Earth's compressional foreshock boundary revisited: Observations by the ISEE-1 magnetometer J. Geophys. Res., submitted, 1986.

Greenstadt, E. W., I, M Green, G. T. Inouye, A. J. Hundhausen, S. J. Bame and I. B. Strong, Correlated magnetic field and plasma observations of the earth's bow shock, J. Geophys. Res., 73, 51, 1968.

Hoppe, M. M. and C. T. Russell, Particle acceleration at planetary bow shock waves, Nature, 295, 41-42, 1982.

Means, J. D., Use of the three-dimensional covariance matrix in analyzing the polarization properties of plane waves, J. Geophys. Res., 77, 5551, 1972.

Odera, T. J., Solar wind controlled pulsations: A review, Rev. Geophys., 24, 55-74, 1986.

Paschmann, G., N. Sckopke, J. R. Asbridge, S. J. Bame, and J. T. Gosling, Energization of solar wind ions by reflection from the earth's bow shock, J. Geophys. Res., 85, 4689, 1980.

Russell, C. T., The ISEE-1 and -2 fluxgate magnetometers, IEEE Trans. Geosci. Remote Sensing, DE-16, 239-242, 1978.

Russell, C. T., E. J. Smith, B, T. Tsututani, J. T. Gosling and S. J. Bame, Multiple spacecraft observations of interplanetary shocks: Characteristics of the upstream ULF turbulence, in Solar Wind Five (edited by M. Neugebauer), pp. 385-400, NASA Conference Publication 2280, Washington, D.C., 1983.

Schwartz, S. J., M. F. Thomsen and J. T. Gosling, Ions upstream of the earth's bow shock: A theoretical comparison of alternative source populations, J. Geophys. Res., 88, 2039, 1983.

Sentman, D. D., J. P. Edmiston and L. A. Frank, Instabilities of low frequency, parallel propagating electromagnetic waves in the earth's foreshock region, J. Geophys. Res., 86, 7487-7497, 1981.

Sonnerup, B. U. O., Acceleration of particles reflected at a shock front, J. Geophys. Res., 74, 1301, 1969.

Southwood, D. J., W. A. C. Mier-Jedrzejowicz and C. T. Russell, The fluxgate magnetometer for the AMPTE UKS subsatellite, IEEE Trans. Geosci. Remote Sensing, GE-23, 301-304, 1985.

Tidman, D. A. and N. A. Krall, Shock Waves in Collisionless Plasmas, 175 pp., Wiley-Interscience, New York, 1971.

Figure Captions

Figure 1. The magnetic power spectra, time series and foreshock geometry on October 19, 1984 (day 293). The upper right-handed panel shows the magnetic field at one second resolution in solar ecliptic coordinates obtained by the UKS satellite. The lower right-hand panel shows the corresponding measurements obtained by the ISEE-2 spacecraft. The upper left panel shows the power spectrum obtained through a Fast Fourier Transform of the displayed time series. The power from all three sensors has been summed. The heavy line corresponds to the data from ISEE-2. The lower right-hand panel shows the location of the spacecraft in the B-V plane, the plane containing the magnetic field, the solar wind velocity vector and the spacecraft. The B-V planes of the two spacecraft are in fact different but have been superimposed for easy comparison of the relative position of the spacecraft. The information on spacecraft position, the vector magnetic field, and the solar wind density and velocity used to construct this panel is given in Table 1.

Figure 2. The magnetic power spectra, time series and foreshock geometry on October 23, 1984 (day 297).

Figure 3. The magnetic power spectra, time series and foreshock geometry on October 30, 1984 (day 304).

Figure 4. The magnetic power spectra, time series and foreshock geometry on November 5, 1984 (day 310) from 1225 to 1233 UT. The B-V planes through ISEE and UKS are separated by 8.3 R_E at this time.

Figure 5. The magnetic power spectra, time series and foreshock geometry on November 5, 1984 (day 310) from 0925 to 0941 UT. The B-V planes through ISEE and UKS are separated by 5.1 R_E at this time.

Figure 6. The magnetic power spectra, time series and foreshock geometry on October 6, 1984 (day 280). The B-V planes through ISEE and UKS are separated by 5.8 R_E at this time.

Figure 7. The magnetic power spectra, time series and foreshock geometry on October 14, 1984 (day 288). The B-V planes through ISEE and UKS are separated by 0.8 R_E at this time.

Figure 8. The magnetic power spectra, time series and foreshock geometry on October 29, 1984 (day 301). The B-V planes through ISEE and UKS are separated by 8.4 R_E at this time.

Figure 9. The magnetic power spectra, time series and foreshock geometry on October 27, 1984 (day 301). The B-V planes through ISEE and UKS are separated by 4.3 R_E at this time.

Figure 10. The magnetic power spectra, time series and foreshock geometry on November 26, 1984 (day 331). The B-V planes through ISEE and UKS are separated by 0.8 R_E at this time.

Figure 11. The ellipticity of the waves near the peak of the power spectrum as a function of the fractional amplitude of the waves. The ellipticity is determined using the Means (1972) technique and is defined as being the ratio of the minor to major axis of the perturbation ellipse. The orientation of the normal to the perturbation ellipse is determined from the quadrature power in the Means technique. The fractional amplitude is the square root of the total power under the spectral peak divided by the background field strength. The bandwidth used in this analysis is given for each event in Table 2.

Table 1

Parameters used in Calculating Foreshock Geometry

	GSE Location (R_E)				
Event	ISEE	UKS	B(nT)	N(cm^{-3})	V(kms^{-1})
October 19	(21.3, 4.6, -1.8)	(11.1, -7.4, 0.4)	(-10.4,9.3,-1.0)	7.1	540
October 23	(13.7,-2.2,-5.4)	(15.9,-8.0, 0.2)	(-4.9,-0.9, 2.4)	7.0*	650
October 30	(14.2,-3.8,-5.2)	(12.5,-9.9, 0.2)	(3.9,-2.5, 1.8)	6.0	360
November 5A	(20.0, 1.0, 1.3)	(15.8,-10.2,-0.2)	(4.3, 0.1, 1.7)	4.0	550
November 5B	(21.0, 0.2, 0.5)	(15.0,-10.8,-0.1)	(4.1,-0.2,-0.1)	3.9	565
October 6	(11.1, 0.2,-5.3)	(14.0,-4.7, 0.5)	(8.5,-5.7, 0.0)	3.8	565
October 14	(20.5, 4.8,-3.2)	(18.3,-4.2, 0.1)	(4.2,-1.3, 0.6)	1.5	550
October 29	(17.7, 4.2, 2.2)	(16.4,-4.8,-0.3)	(6.0,-0.8, 0.9)	6.2	435
October 27	(14.0, 5.3, 3.3)	(17.2,-7.6,-0.1)	(4.9,-1.5,-0.1)	4.0	440
November 26	(17.5,-10.4,-3.2)	(12.2,-10.0,-0.6)	(2.4, 0.1, 0.2)	4.2	370

*Assumed value

Table 2

Wave Properties at Spectral Peaks

Event	Spacecraft	Frequency Band (Hz)	Weighted Frequency (Hz)	Propagation Angle	Eccentricity	Percent Polarization
October 19	UKS	.018-.082	.051	23°	-.73	58
October 23	ISEE	.019-.039	.030	44°	.59	36
October 30	UKS	.015-.034	.025	65°	.34	74
	UKS+	.08-.27	.12	20°	.91	80
	ISEE+	.08-.27	.16	17°	.94	98
November 5A	UKS	.01-.05	.033	37°	.67	21
	ISEE	.02-.05	.038	14°	.61	57
November 5B	UKS	.02-.03	.025	36°	.57	45
	UKS+	.03-.05	.035	41°	.68	36
	ISEE	.03-.05	.036	59°	-.34	50
October 6	UKS	.04-.07	.054	9°	-.47	32
	ISEE	.05-.07	.062	19°	-.75	76
October 14	UKS	.01-.05	.028	53°	.45	40
	ISEE	.01-.05	.029	80°	-.16	68
October 29	UKS	.01-.04	.028	15°	.77	20
	ISEE	.01-.04	.028	72°	-.12	58
October 27	UKS	.02-.04	.032	13°	.58	61
	ISEE	.02-.05	.036	10°	.63	31
November 26	UKS	.02-.05	.030	12°	.64	68
	ISEE	.01-.03	.018	31°	-.67	88

+ Not used in Figure 11

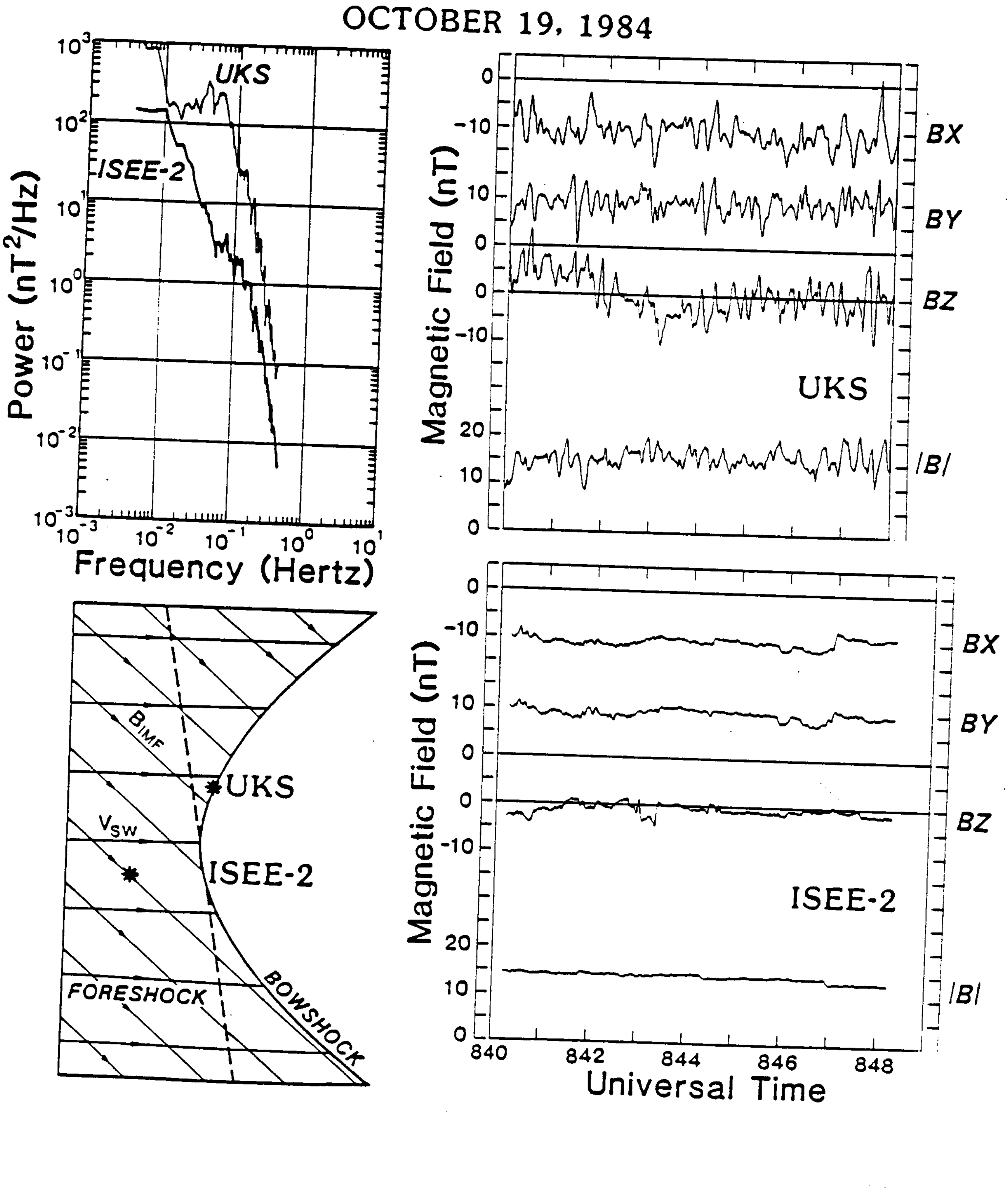

OCTOBER 19, 1984
Power (nT^2/Hz)
Frequency (Hertz)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
UKS
ISEE-2
Magnetic Field (nT)
BX
BY
BZ
|B|
UKS
0
-10
10
0
0
-10
20
10
0
Magnetic Field (nT)
BX
BY
BZ
|B|
ISEE-2
0
-10
10
0
0
-10
20
10
0
840
842
844
846
848
Universal Time
B_{IMF}
UKS
V_{SW}
ISEE-2
FORESHOCK
BOWSHOCK

Figure 1

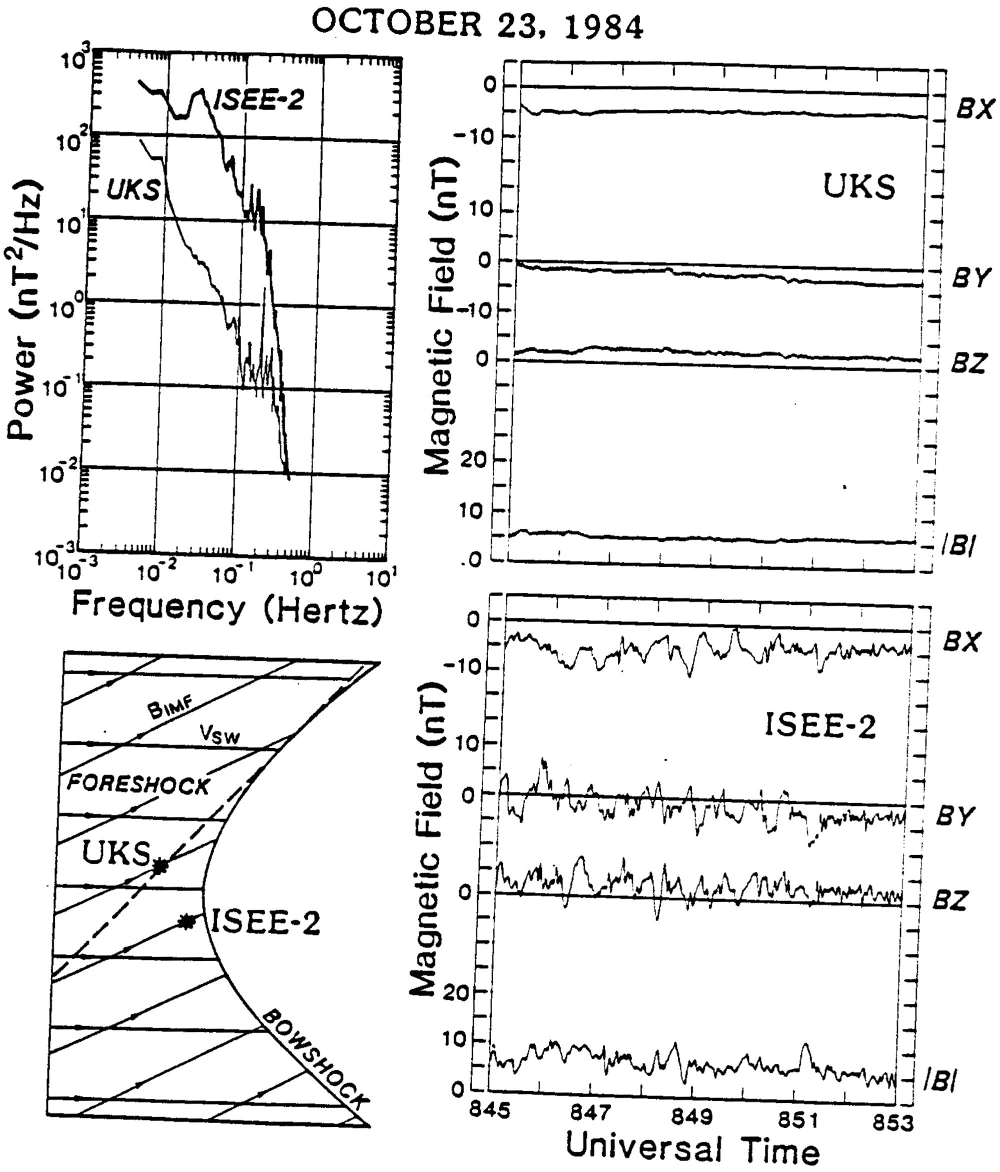
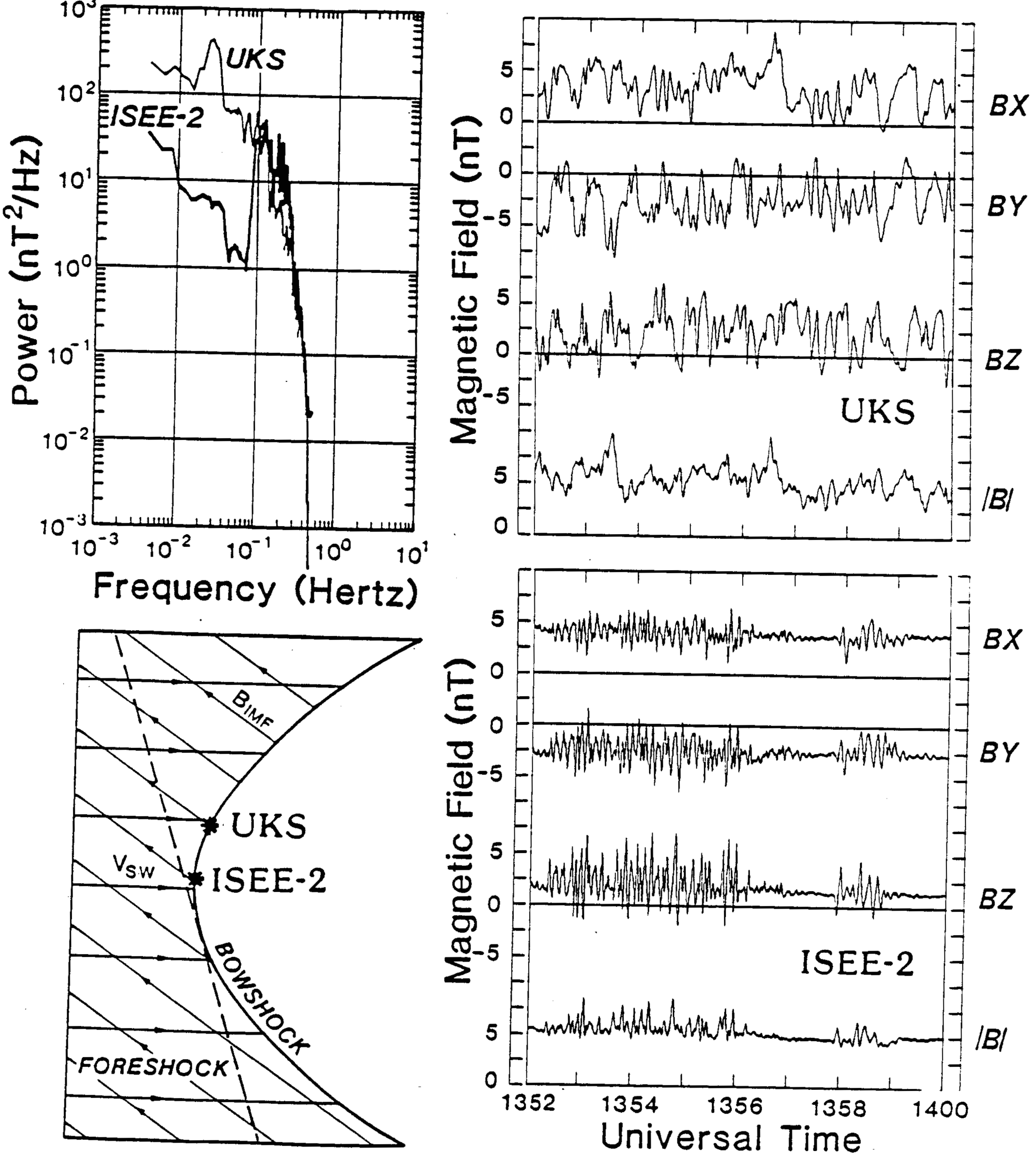
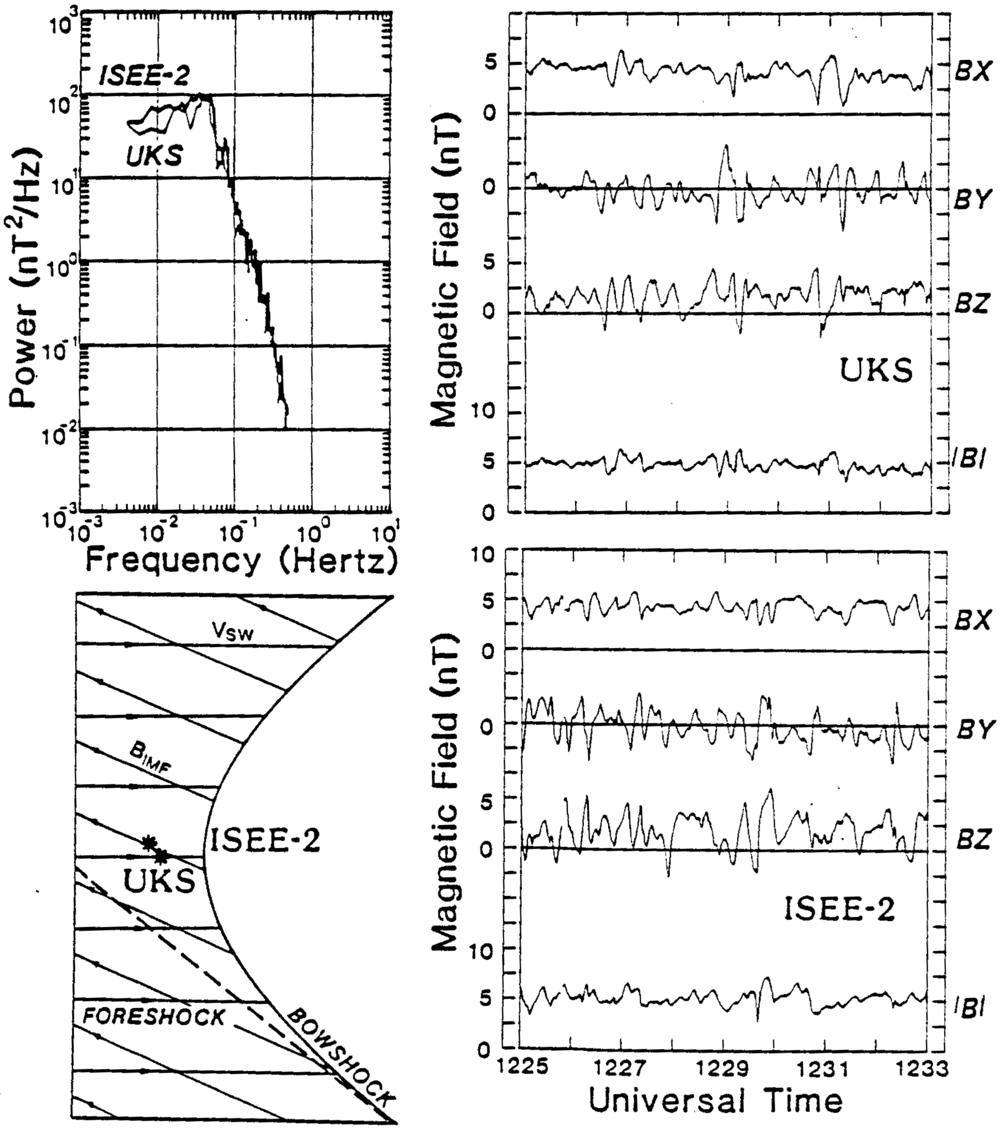

OCTOBER 23, 1984
Power (nT²/Hz)
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
ISEE-2
UKS
10⁻³
10⁻²
10⁻¹
10⁰
10¹
Frequency (Hertz)
BIMF
VSW
FORESHOCK
UKS
ISEE-2
BOWSHOCK
Magnetic Field (nT)
0
-10
10
0
-10
0
20
10
0
UKS
BX
BY
BZ
/B/
Magnetic Field (nT)
0
-10
10
0
0
20
10
0
ISEE-2
BX
BY
BZ
/B/
845
847
849
851
853
Universal Time

Figure 2

OCTOBER 30, 1984



NOVEMBER 5, 1984



NOVEMBER 5, 1984

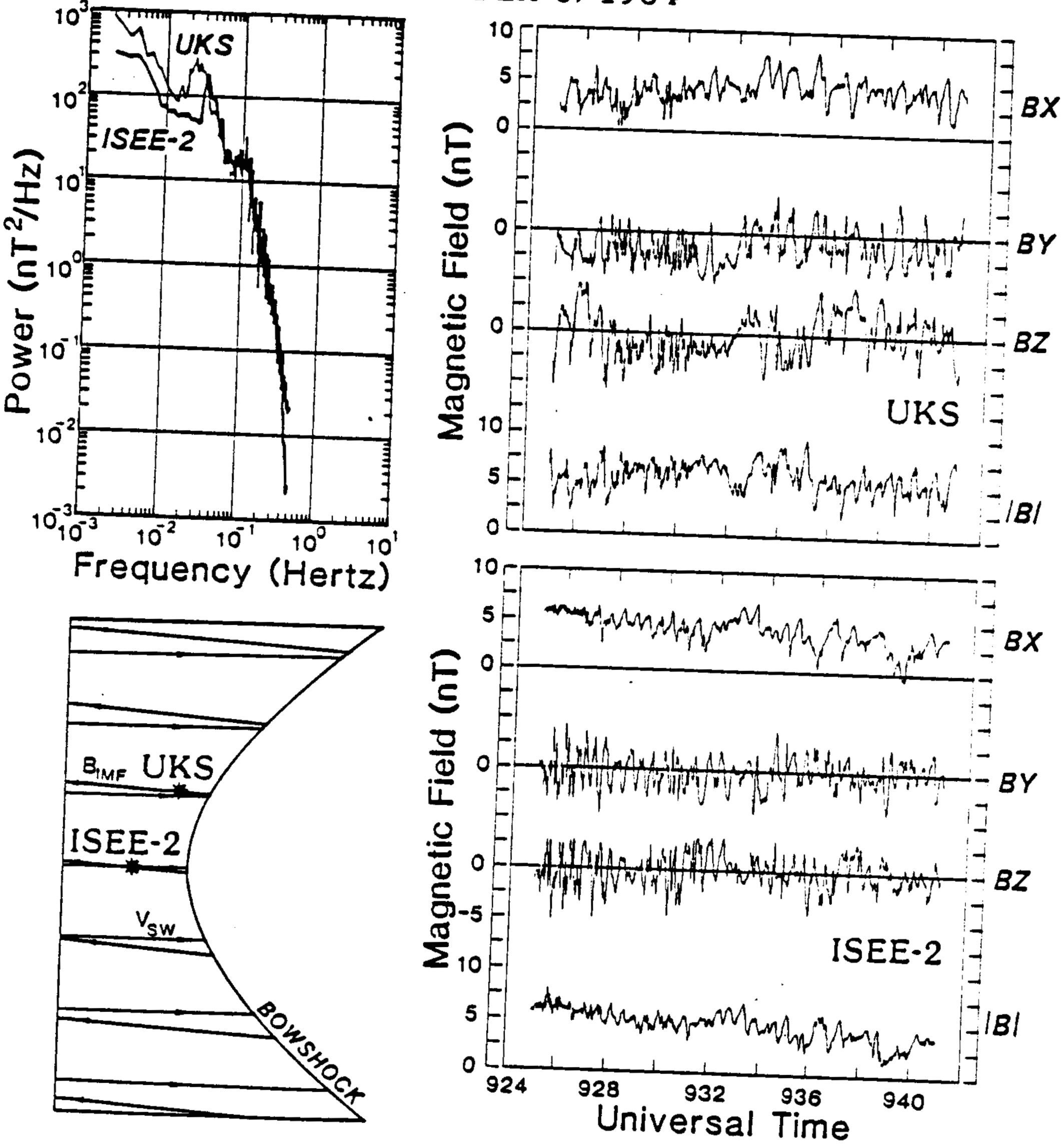


Figure 5

OCTOBER 6, 1984

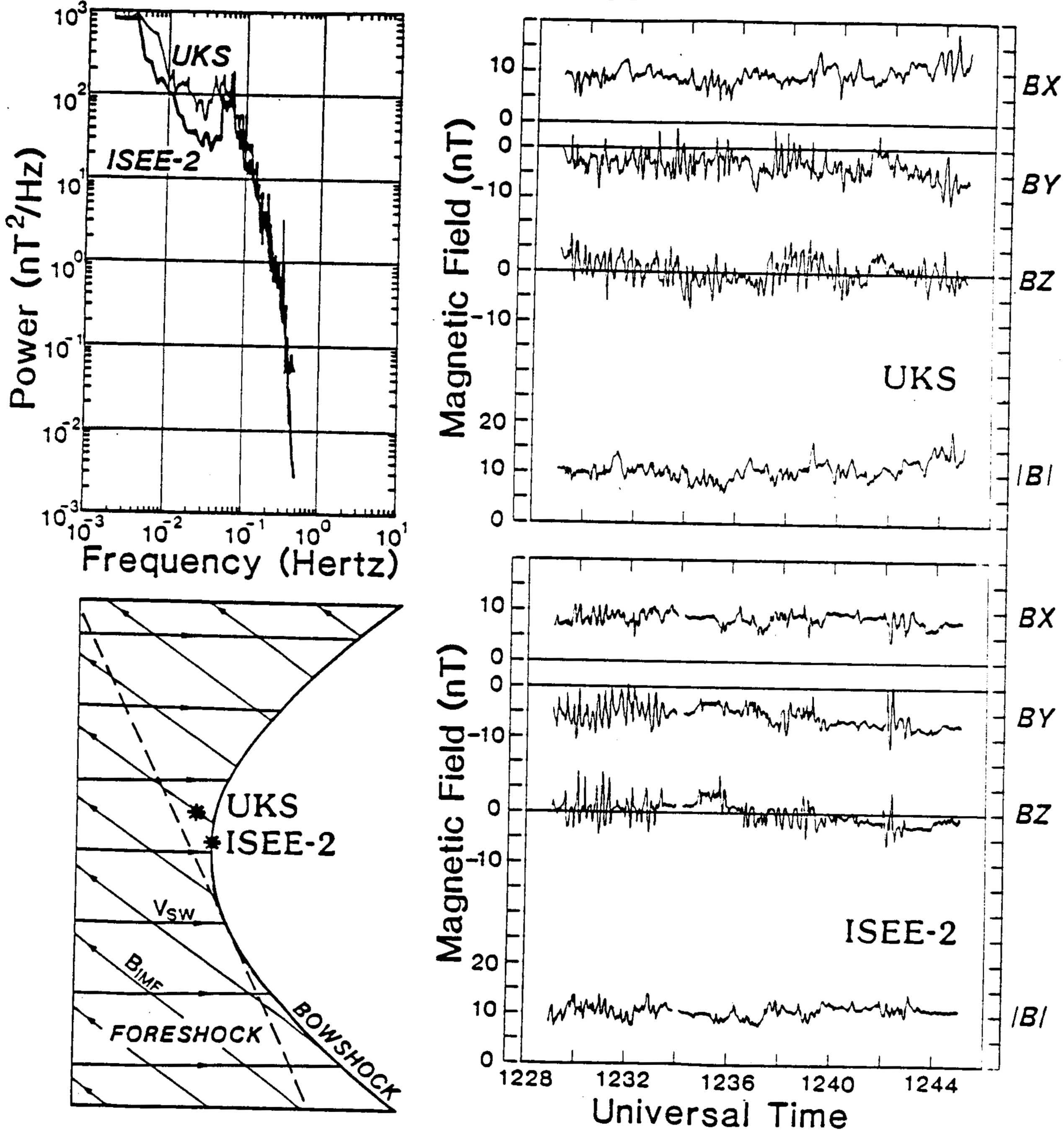
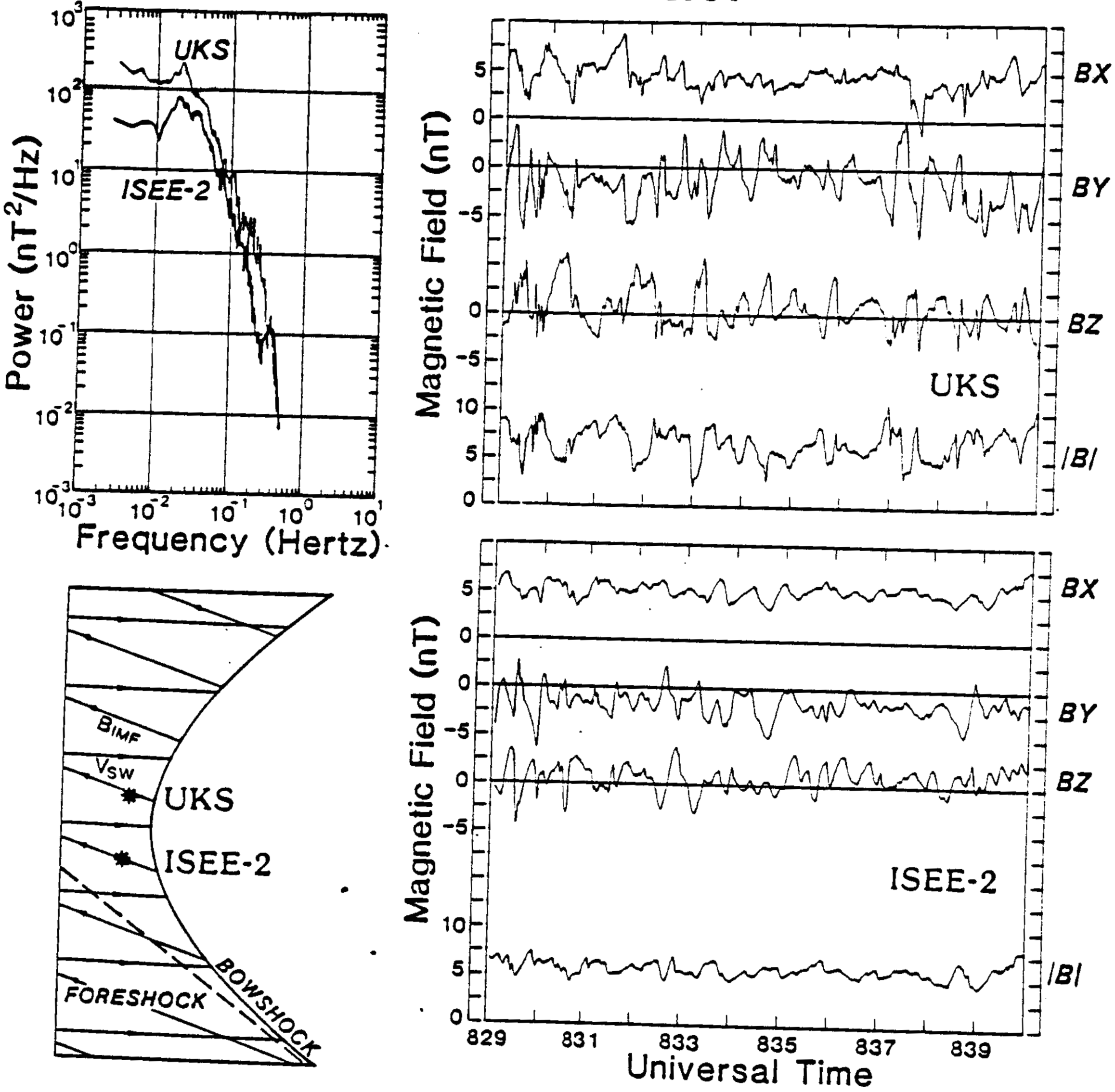


Figure 6

OCTOBER 14, 1984



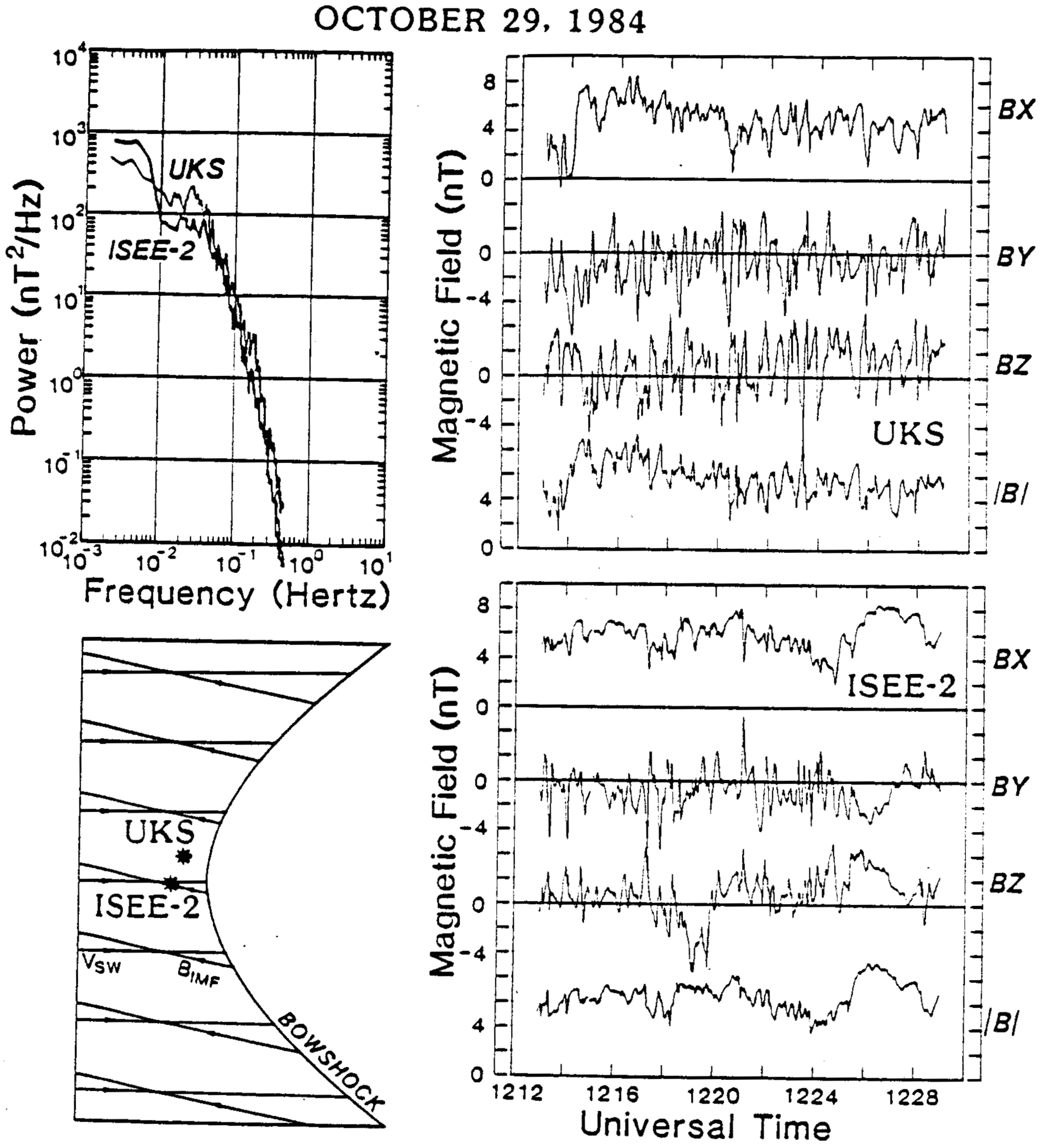

OCTOBER 29, 1984
Power (nT²/Hz)
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻²
10⁻¹
10⁰
10¹
Frequency (Hertz)
UKS
ISEE-2
Magnetic Field (nT)
8
4
0
-4
BX
BY
BZ
|B|
UKS
ISEE-2
1212
1216
1220
1224
1228
Universal Time
V_SW
B_IMF
BOWSHOCK

Figure 8

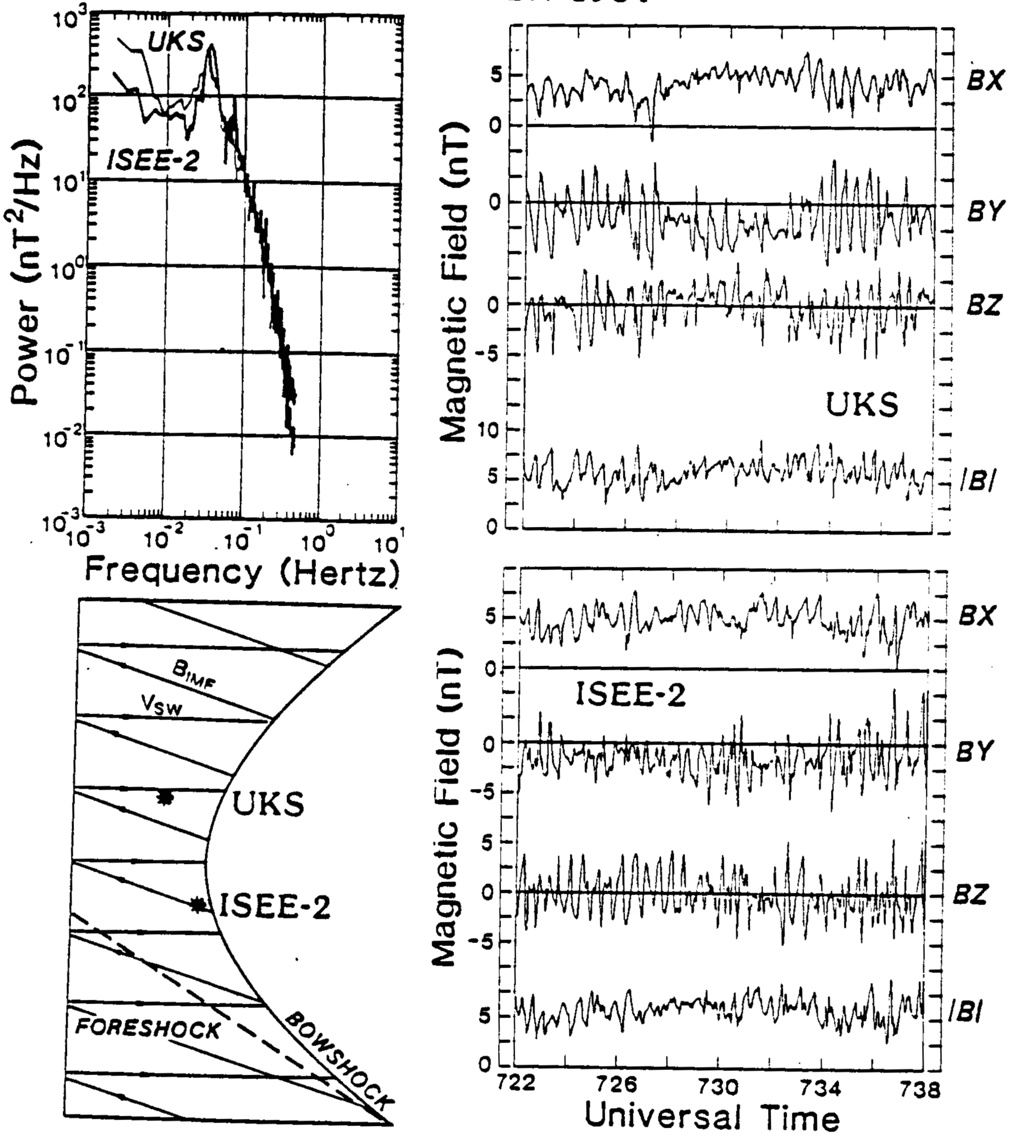

OCTOBER 27, 1984

Figure 9

NOVEMBER 26, 1984

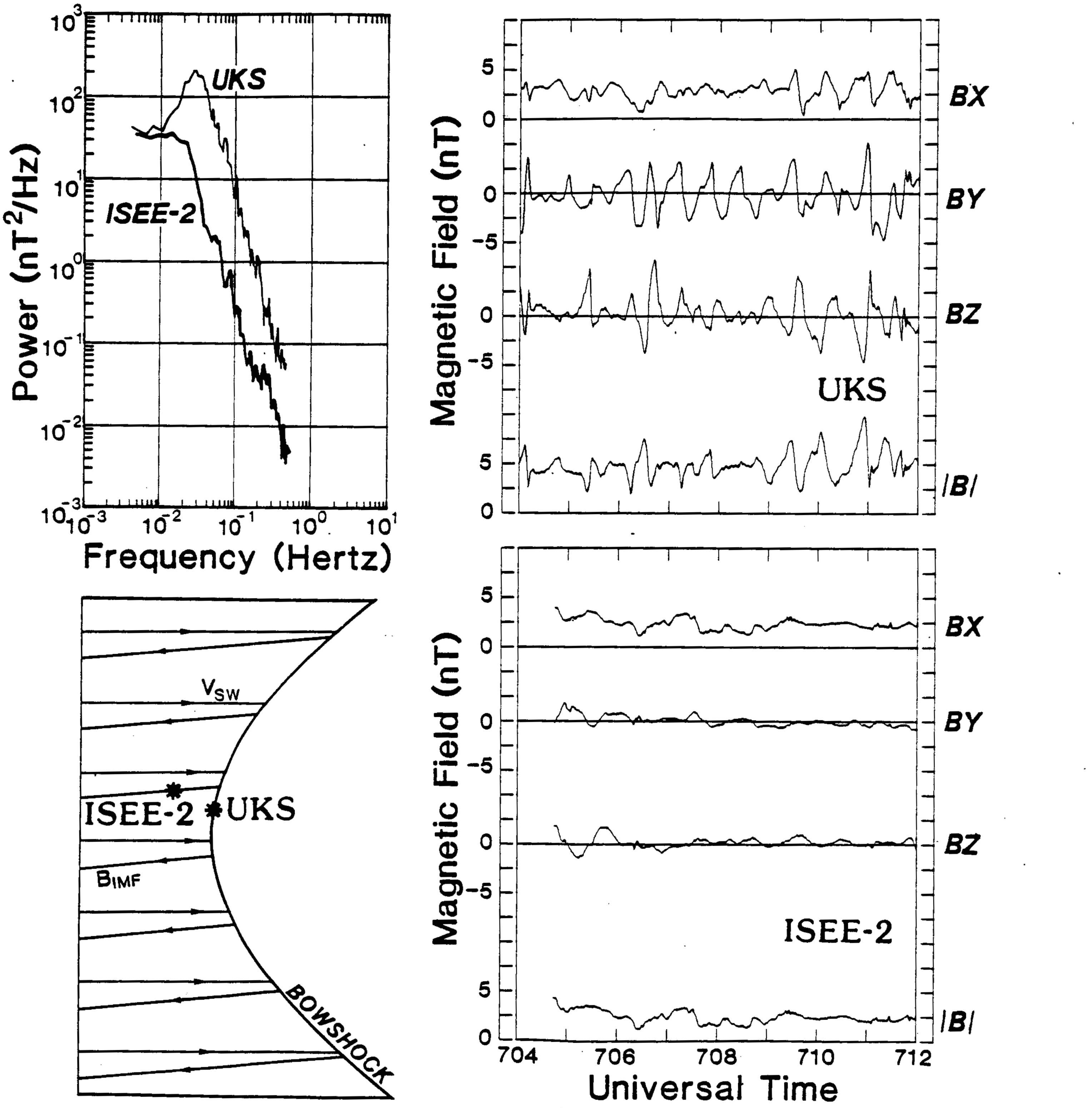
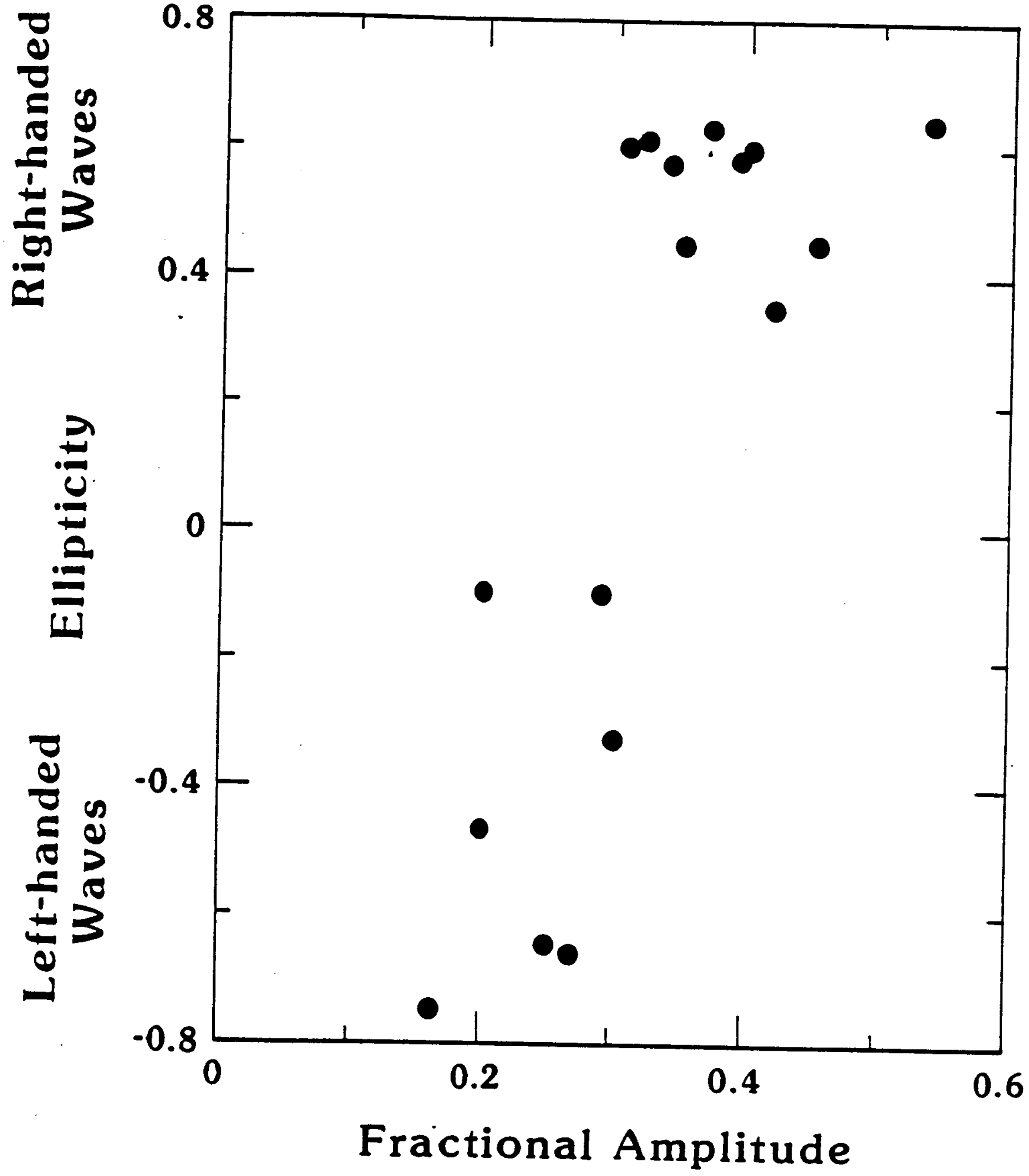


Figure 10


Right-handed Waves
Ellipticity
Left-handed Waves
0.8
0.4
0
-0.4
-0.8
0
0.2
0.4
0.6
Fractional Amplitude

SIMULTANEOUS MEASUREMENTS OF THE MAGNETOPAUSE AND FLUX TRANSFER EVENTS AT WIDELY SEPARATED SITES BY AMPTE-UKS AND ISEE-1 AND 2

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November 10 1986

Abstract. On 19 September 1984 the ISEE-1 and 2 and AMPTE-UKS and IRM spacecraft pairs crossed the dayside magnetopause at nearly the same universal time and magnetic local time but at much different latitudes. This fortuitous occurrence allows the magnetopause and flux transfer events (FTE's) to be studied at two widely separated sites at the same time. The magnetopause crossing locations and inferred normals indicate that no single simple symmetric magnetopause surface can describe the boundary at this time. Flux transfer events (FTE's) are observed at both locations, those at UKS having standard normal component signatures, while those at ISEE have reverse signatures. The FTE's at UKS, closer to the equator, appear to have less helicity, or "twistedness" than those at ISEE far to the south. FTE disturbances exhibit little coherence between sites. While within the magnetosphere, the spacecraft observe a coherent field rarefaction coupled with a tilt; we speculate that the signature is associated with dayside magnetopause reconnection.

Introduction

Our understanding of the magnetopause has increased substantially in recent years, not least because of the ISEE spacecraft mission and associated activities. ISEE 1 and 2 measurements were important in opening up the investigation of the small scale (< 1 RE, Earth radius) structure of phenomena in the boundary vicinity and in particular in distinguishing space from time variation. The ISEE separations rarely exceeded about 1 RE and there have been few opportunities to examine magnetopause phenomena on longer spatial scales. Opportunities arose for correlative studies on larger scale lengths in the fall of 1984 when the AMPTE IRM and UKS spacecraft joined ISEE 1 and 2 in orbits with similar apogee distances and local time but different orbital inclination.

On 19 September 1984 the ISEE-1 and 2 and AMPTE-UKS and IRM spacecraft pairs crossed the dayside magnetopause at nearly the same universal time (1600 UT)and magnetic local time (1100 LT). This interval provides an opportunity to compare the magnetopause and flux transfer events (FTE's) at the two sites. In this paper we shall compare the magnetopause location and orientation, the boundary structure and FTE occurrence and structure at the two sites.

Magnetopause Location and Orientation

At the time considered here, AMPTE and ISEE spacecraft were outbound from perigee and in the dayside magnetosphere. Figure 1 shows the trajectories of the spacecraft in GSM coordinates. Tick marks on the trajectories occur every fifteen minutes. At 1600 the spacecraft were separated by only 1 Re in Y GSM, but by 6 Re in Z GSM. ISEE and AMPTE could thus sample, respectively, the off-equatorial and near-equatorial magnetopause in the northern and southern hemispheres at roughly the same magnetic local time. Also shown in Figure 1 are filled circles showing the initial magnetopause locations seen by AMPTE and ISEE.

The dashed line shows the nominal position of the magnetopause as given by Fairfield (1971). The magnetopause position recorded at both locations is well inside its average position.

Figure 2 gives an overview of UKS and ISEE-1 and 2 4-second resolution magnetic field data between 1545 and 1645 UT. We have examined the five second resolution IRM data for this period; UKS and IRM are so close that the records are effectively identical throughout. We shall only use UKS data here. The field components are displayed in a boundary normal coordinate system in which the L component is aligned with the mean magnetospheric field orientation at each site. In the GSM system, the L coordinate unit vectors are (0.568, -0.003, 0.823); (-0.485, 0.307, 0.819) at ISEE and AMPTE spacecraft respectively. Thus, at ISEE, at higher latitude, the mean field is in a GSM (X,Z) meridian plane tilting at about 40° to the Z axis away from Earth; at the AMPTE spacecraft, the field tilts in the (X,Z) plane at a similar angle, but towards the Earth and with a small Y component.

The normal direction was fixed using the tangential discontinuity assumption, i.e., it is along the normalized cross-product of the mean magnetospheric and magnetosheath fields. The unit vector magnetopause normal for UKS is (0.883, -0.015, 0.469) in GSM while for ISEE-1/2 it is (0.808, -0.191, -0.558).

Figure 2 shows that prior to the first UKS magnetopause encounter at 1559 UT, the magnetic field behavior at the ISEE and AMPTE spacecraft is similar; a depression in the total field is followed by a rise in strength before UKS meets the boundary. The depression is accompanied by a negative perturbation in Bn at UKS, above the equator, and a larger positive one at ISEE, well below the equator. There are also smaller excursions in the Bm component at each site, which are also in antiphase.

Evident coherent behavior between the spacecraft ceases once UKS crosses the magnetopause at 1559. Two more magnetopause encounters follow at 1602 and 1611. FTE signatures are observed at 1600, 1604, 1607, and possibly at 1614 and 1630; the UKS tracking period ended shortly afterwards. ISEE-2 crosses the magnetopause at 1625, 1626, and 1632, and very clear FTE signatures in Bn can be seen at 1616, 1622, 1627, 1636, 1638 and 1641. There may also be FTE's at 1620, 1625 and 1630. Some 1200 km behind ISEE-2 along the orbit, ISEE-1 does not cross the magnetopause until after 1634, although all the ISEE-2 FTE's show up in the ISEE-1 data as well.

Magnetopause Shape

Commonly the magnetopause is described as a conic of rotation about the Sun-Earth line. Figure 3 shows the UKS and ISEE trajectories rotated into the plane containing the spacecraft position and the Sun-Earth line. Also shown are the projections of the two magnetopause normals into this plane. From the position of the magnetopause and its normal at that point it is possible to determine the conic section (with Earth at one focus) that fits that position and normal. These are shown for UKS and ISEE as the dotted and solid curves, respectively.

It can clearly be seen that the magnetopause is distorted in shape. At 1600, when UKS first encounters the magnetopause, ISEE-1 and 2 are still well inside the boundary, whereas the UKS-derived magnetopause places ISEE outside the magnetopause at this time. Likewise when ISEE crosses the magnetopause near 1630, UKS is outside the boundary, while the ISEE-derived magnetopause places UKS inside the boundary. Moreover, up to 1630, little FTE activity is seen at UKS suggesting that the spacecraft remains well outside the boundary. No symmetric conic of a single eccentricity can account for the magnetopause position and shape at this time.

The field perturbations in the normal direction prior to 1559 seen at both spacecraft sites could reflect a change in magnetopause shape. The direction change at UKS is not great but at ISEE, farther from the equator, the direction changes by about 15° in the meridian tilting away from the Earth. The field at UKS, above the equator, tilts more towards the Earth.

One potential explanation is that reconnection is initiated on the dayside magnetopause somewhere near noon at about 1545 when the perturbation starts. The gradual tilting in the field at both ISEE and AMPTE spacecraft results from the equatorial part of the local field lines being sucked towards the reconnection site. The rarefaction in field strength could result from the same effect. As the reconnection rate drops, field tilt decreases and compression increases. The net erosion of the magnetopause has moved the boundary very close to UKS which exits very soon after. Field compression is often seen immediately adjacent to the magnetopause; this is the first evidence that it is a temporal rather than spatial effect.

FTE Occurrence and Structure

It is clear from Figure 2 that FTE activity is present simultaneously at ISEE-1/2 in the southern hemisphere and

AMPTE-UKS in the northern hemisphere. There is no one-to-one correspondence evident between individual events detected at the two sites. The Russell and Elphic (1978) connected tube hypothesis suggests that one might expect a simple relation. If, as has been proposed (Russell et al., 1985; Southwood et al., 1986), FTE's originate in the equatorial region, UKS should observe the signatures of northward moving tubes first. There could be a time delay (of up to a minute or so) before ISEE-1/2, roughly 2 Re farther from the subsolar point, observes the southern counterpart. In the 4-second time series data in Figure 2, none of the UKS FTE's has an unambiguous ISEE counterpart at the expected time. However, the picture is not simple. Close examination of the records reveals a variety of smaller amplitude disturbances on various time scales; more sophisticated analysis is needed.

Complicating the comparison of FTE occurrence are the differences in amplitude at each site. The range of peak-to-peak Bn amplitudes for the five FTE's seen on UKS extends from 15 to 38 nT, with a mean of 26 nT; the five largest ISEE-2 amplitudes range from 20 to 53 nT, with a mean of 39 nT. In the Russell and Elphic interpretation (and many developments of it), when a spacecraft grazes a FTE, the observed Bn signatures is due to the disturbance or "draping" field around the FTE flux tube (Farrugia et al., 1986). However, the Bn signature is also detected within the open part of the tube where, as pointed out by Cowley

(1982) and Paschmann et al. (1982), it indicates the presence of field-aligned currents within the FTE twisting the field. The events seem of similar duration at the two sites (thus the smaller Bn does not reflect smaller cross-section). The FTE's observed at the ISEE location seem to be more twisted up than those at the UKS location.

In addition to the lower amplitude of the signals at UKS, there is another important distinction between events detected at the two sites. The FTE Bn variations shown in the UKS plot are all standard (S) bipolar signatures, i.e., a positive followed by a negative excursion. The ISEE Bn signatures are all reverse (R) signatures, negative followed by positive excursions. This is consistent with the earlier statistical results (Rijnbeek et al., 1984; Berchem and Russell, 1984; Southwood et al., 1986) which showed that S (R) events were predominant above (below) the equator.

Summary and Discussion

This paper presents the first reports of simultaneous measurements at the magnetopause from spacecraft separated by more than 10,000 km. In the case reported here, the spacecraft, the ISEE 1/2 pair and the UKS/IRM pair of the AMPTE mission, are near the noon meridian but at very different latitudes. Our preliminary study shows that the measurements have fulfilled some expectations but that important questions remain for further study.

Magnetopause location and shape, as inferred from boundary normals, suggests that the boundary cannot be instantaneously represented by a simple symmetric conic surface. At the time that UKS exits the magnetosphere, the conic section magnetopause predicts ISEE in the sheath when it is still in the magnetosphere. When ISEE later exits, the UKS position predicted by the appropriate conic section is inside the magnetosphere and thus again inconsistent.

The first exit of UKS from the magnetosphere is preceded by a signature that is similar at both spacecraft. A dip in field strength accompanied by a bending of the field corresponds to the outward displacement of the plasma and field in the equatorial regions. This in turn is followed by an increase in field at both spacecraft before UKS leaves the magnetosphere. We speculate that this is symptomatic of a sustained magnetopause erosion.

Whilst the spacecraft were in the magnetopause vicinity FTE's were observed at both sites. Those in the north at UKS show standard Bn signatures indicative of a northward travelling flux tube, while those at ISEE in the south have reverse Bn signatures expected for southward travelling perturbations.

The FTE's at UKS have smaller amplitude Bn signatures and are fewer in number than the FTE's at the ISEE location. We thus have an individual instance consistent with the survey results of Southwood et al. (1986) which found a much lower rate of FTE occurrence at UKS than in the first years of ISEE operation where ISEE was again at higher mean latitude. Southwood et al. (1986) and also Saunders et al. (1986), who specifically compared the UKS results with the ISEE statistics, have argued that the survey result was due to the lower average latitude of the UKS measurements.

We have argued that the larger Bn signature is likely to imply that the field becomes more twisted as events move away from the equator. More analysis is required to confirm that the actual duration of events is similar at each site before the conclusion is secure.

There is no evident one-to-one correspondence of FTE's seen at the two sites. In light of the disturbed nature of the field near the boundary and potential systematic amplitude and duration differences between sites we intend to investigate this question further. The question has a bearing on whether FTE's are due to connected tube formation (patchy reconnection: Russell and Elphic, 1978) or whether they are a manifestation of tearing mode phenomena (Lee and Fu, 1985). In the Lee and Fu picture, tearing islands forming at the equatorial magnetopause could develop in the north and south independently and convect away independently: no correspondence would necessarily be seen between the UKS and ISEE FTE's.

Acknowledgements

We wish to thank C.T. Russell for helpful discussions. IRM data was kindly provided by H. Luehr and W. Baumjohann. This work was supported by NASA grants, NAG5-536 and NAS5-28448. Work at Imperial College, including provision of the AMPTE-UKS magnetometer, was funded by the U.K. Science and Engineering Research Council.

References

Berchem, J., and C.T. Russell, Flux transfer events on the magnetopause: Spatial distribution and controlling factors, **J. Geophys. Res.**, **89**, 6689, 1984

Cowley, S.W.H., The causes of convection in the Earth's magnetosphere - a review of developments during the IMS, **Rev. Geophys. Space Phys.**, **20**, 531, 1982

Fairfield, D.H., Average and unusual locations of the Earth's magnetopause and bow shock, **J. Geophys. Res.**, **76**, 6700, 1971

Farrugia, C.J., R.C. Elphic, D.J. Southwood, and S.W.H. Cowley, Field and flow perturbations outside the open field region in flux transfer events. 1. Theory, **Planet. Space Sci.**, 1986

Lee, L.C. and Z.F. Fu, A theory of magnetic flux transfer at the Earth's magnetopause, **Geophys. Res. Lett.**, **12**, 105, 1985

Paschmann, G., G. Haerendel, I. Papamastorakis, N. Sckopke, S.J. Bame, J.T. Gosling and C.T. Russell, Plasma and magnetic field characteristics of magnetic flux transfer events, **J. Geophys. Res.**, **87**, 2159, 1982

Rijnbeek, R.P., S.W.H. Cowley, D.J. Southwood and C.T. Russell, A survey of dayside flux transfer events observed by ISEE 1 and 2 magnetometers, **J. Geophys. Res.**, **89**, 786, 1984.

Russell, C.T. and R.C. Elphic, Initial ISEE magnetometer results: magnetopause observations, **Space Sci. Rev.**, **22**, 681, 1978

Russell, C.T., J. Berchem and J. Luhmann, On the source region of flux transfer events, **Adv. Space Res.**, **5**, 363, 1985

Saunders, M.A., D.J. Southwood, R.P. Rijnbeek, W.A.C. Mier-Jedrzejowicz, and M.W. Dunlop, Detection of FTE's by the AMPTE-UKS magnetometer, **Adv. Space Res.**, (in press), 1986

Southwood, D.J., M.A. Saunders, M.W. Dunlop, W.A.C. Mier-Jedrzejowicz, and R.P. Rijnbeek, A survey of flux transfer events recorded by the UKS spacecraft magnetometer, **Planet. Space Sci.**, (in press), 1986

Figure Captions

Fig. 1. Trajectories of ISEE-1 and 2 and AMPTE-UKS on 19 September 1984 in GSM coordinates. Time ticks are shown every 15 minutes, with hours indicated to one side. Filled circles indicate the first encounter with the magnetopause. The average magnetopause position according to Fairfield (1971) is shown by the dashed curve.

Fig. 2. Time series of UKS (top) and ISEE-1 and 2 (bold and thin traces, respectively in the bottom panel) in boundary normal coordinates. Data points (derived from a centered 12 second average) are plotted every 4 seconds.

Fig. 3. UKS and ISEE trajectories rotated into the plane containing the spacecraft position and the Earth-sun line. Also shown are the magnetopause crossing positions, derived normal directions and inferred magnetopause shapes for ISEE (solid curve) and UKS (dotted curve).

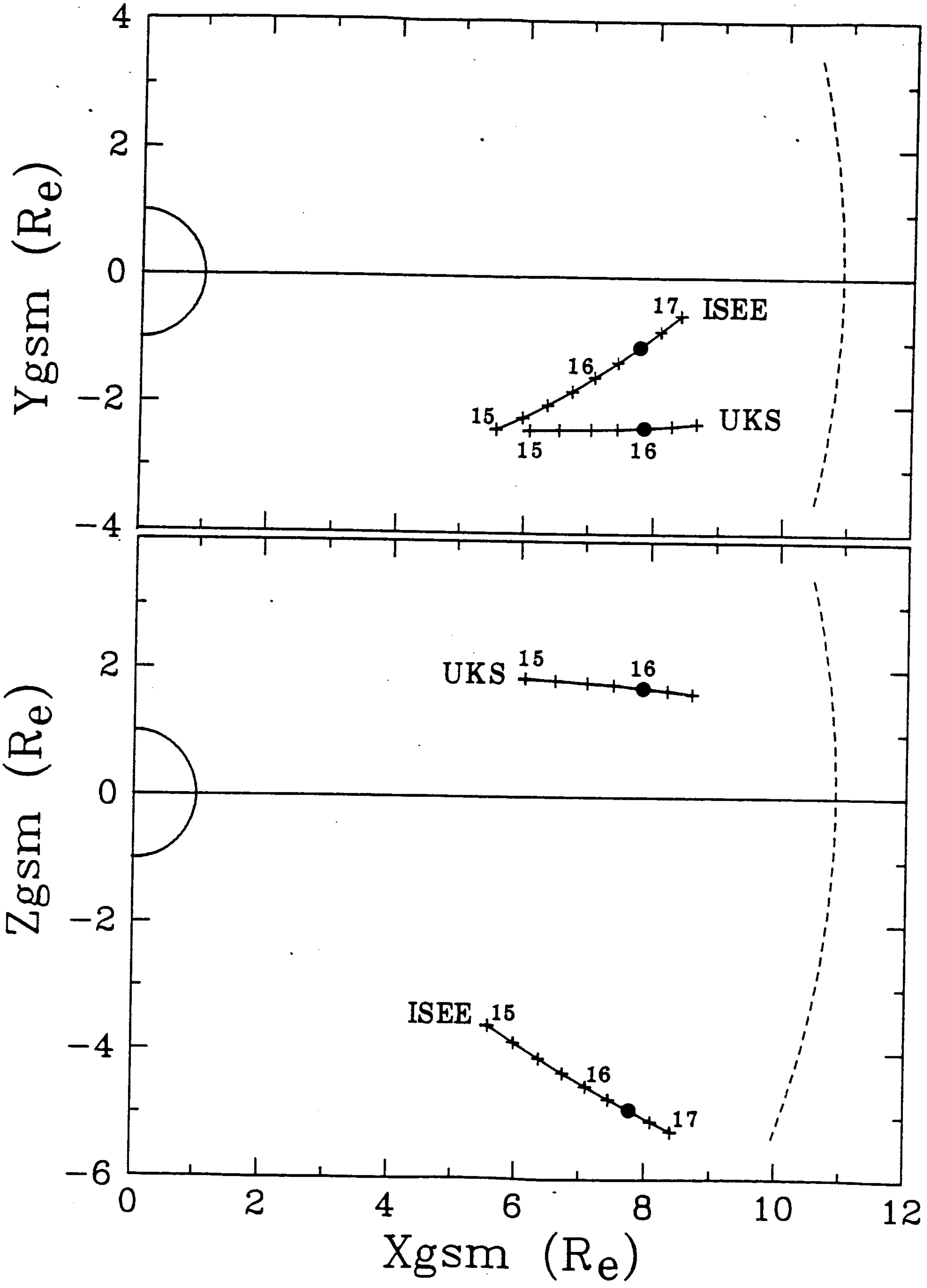
Ygsm (Re)
Zgsm (Re)
Xgsm (Re)
4
2
0
−2
−4
−6
0
2
4
6
8
10
12
ISEE
UKS
15
16
17
15
16
UKS
15
16
ISEE
15
16
17

Fig. 1

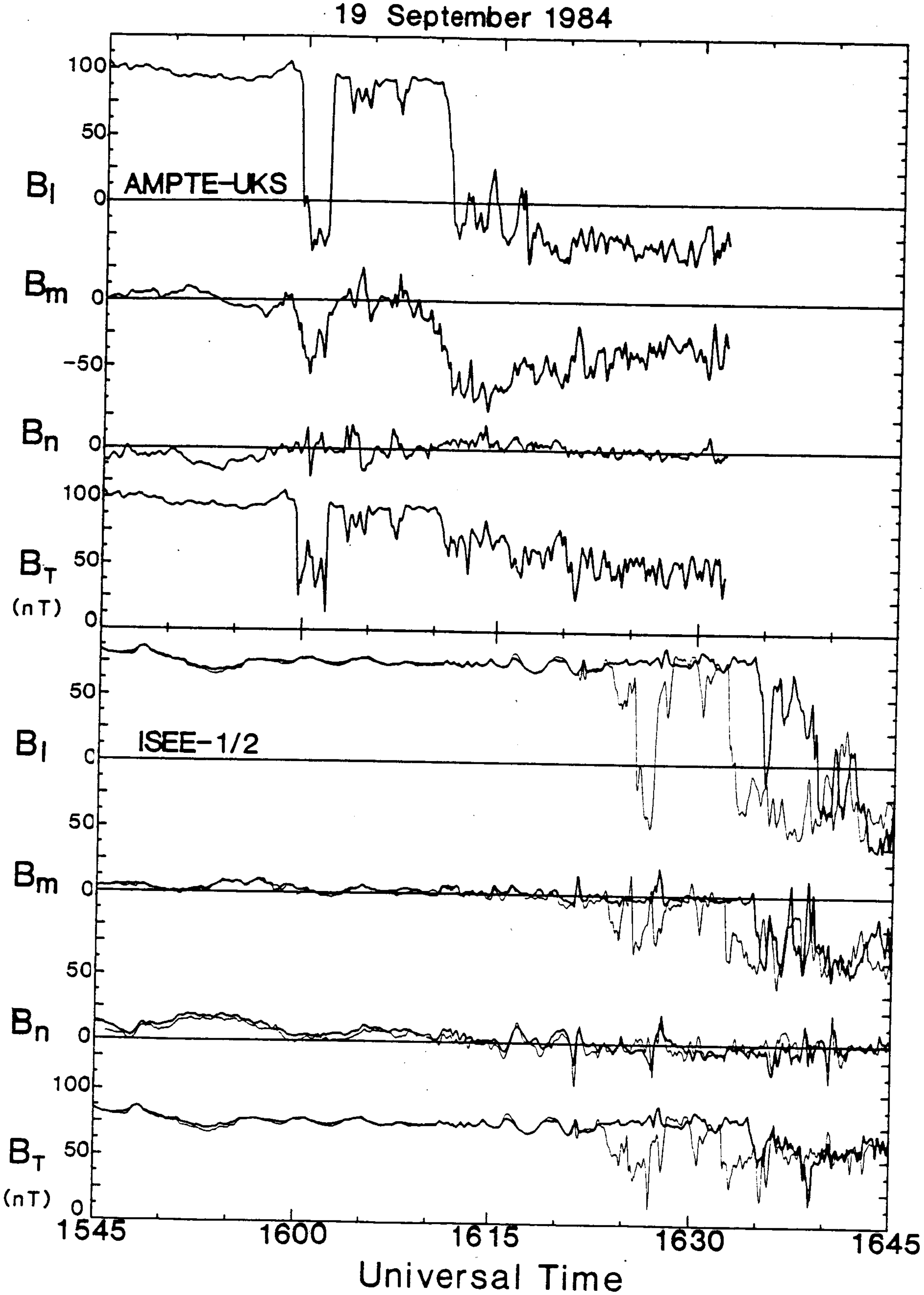
19 September 1984
AMPTE-UKS
ISEE-1/2
B_l
B_m
B_n
B_T
(nT)
100
50
0
-50
1545
1600
1615
1630
1645
Universal Time

Fig. 2

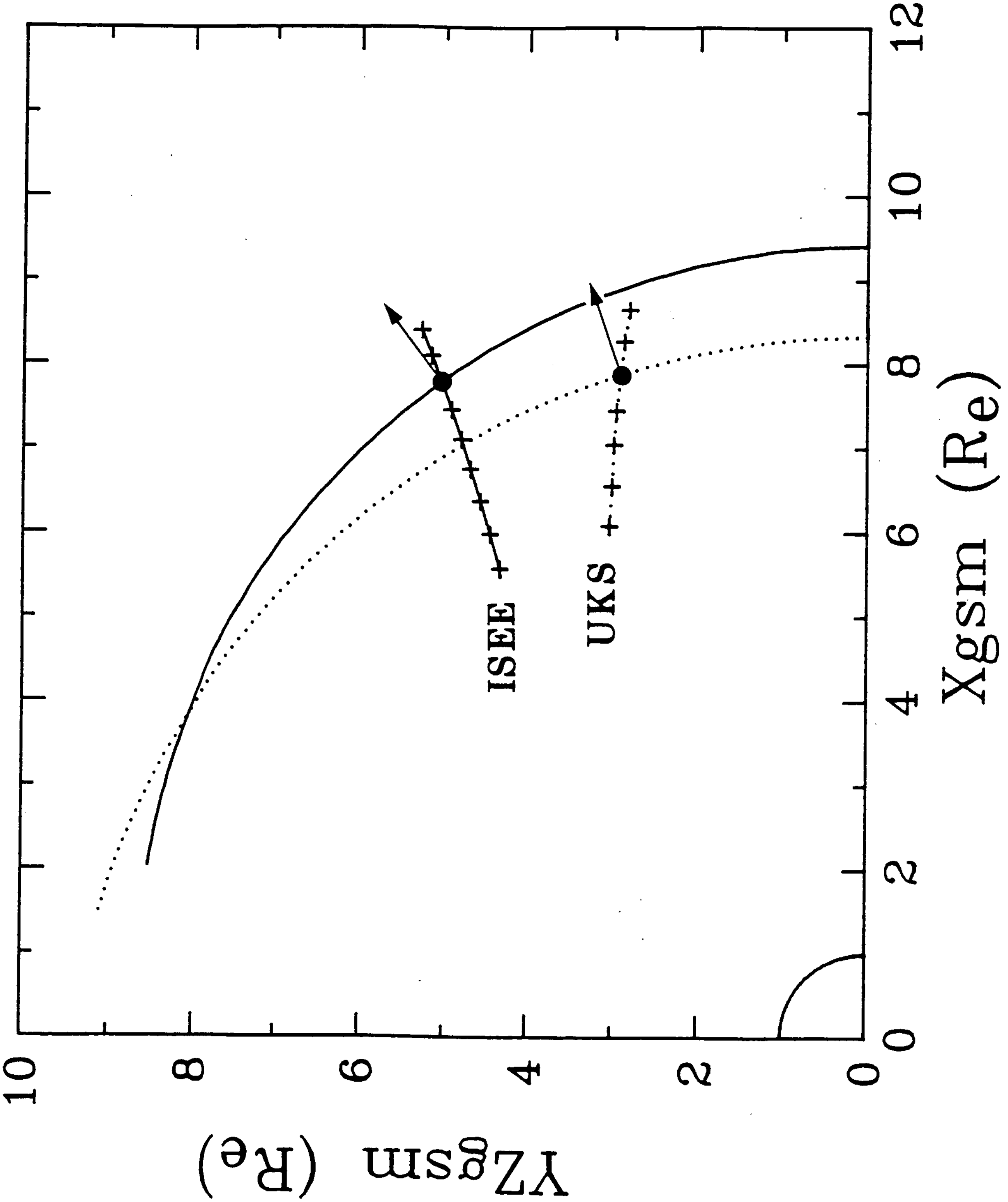

Fig. 3