COMPARISON OF DEEP SPACE AND NEAR-EARTH OBSERVATIONS OF PLASMA TURBULENCE AT SOLAR WIND DISCONTINUITIES

F. L. Scarf, R. W. Fredricks and I. M. Green

An invited review

ABSTRACT

We use simultaneous observations of plasma waves from the electric field instruments on Pioneer 9 and OGO 5 to illustrate the difference between near-earth and deep space conditions. It is shown that the experimental study of true interplanetary wave-particle interactions is difficult to carry out from an earth orbiter because the earth provides significant fluxes of nonthermal particles that generate intense plasma turbulence in the upstream region.

INTRODUCTION

The first extensive measurements of interplanetary parameters were made on the deep space probe Mariner 2. However, most of the experimental information on the solar wind and its interface with the earth has actually come from instrumentation on near-earth satellites such as IMP, OGO, Vela and HEOS. The early Explorer 18 observations suggested that the bow shock represents an abrupt outer boundary of the earth's influence. Therefore, the upstream region was tacitly considered to represent undisturbed interplanetary plasma, essentially identical to that expected in the absence of the earth. Nevertheless, even in 1963–1964, it was known that there were some significant large-scale perturbations associated with the magnetospheric obstacle, and several early reports described nonthermal electron observations upstream from the shock [*Anderson et al.*, 1965; *Anderson*, 1968].

During the past few years it has become clear that the earth does disturb a vast region in the solar wind. Detectable geomagnetic tail phenomena [*Ness et al.*, 1967; *Wolfe et al.*, 1967; *Mariani and Ness*, 1969; *Intriligator et al.*, 1969; *Scarf et al.*, 1970*a*] and wake effects [*Siscoe et al.*, 1970] exist at least 500-1000 R_e downstream, and some direct upstream magnetospheric perturbations are found to extend to the orbit of the moon [*Fairfield*, 1968; *Freeman et al.*, 1970] and beyond.

Ahead of the earth the perturbations involve suprathermal electrons and protons produced near the bow shock. These particles flow upstream and they generate large-amplitude electromagnetic and electrostatic plasma turbulence [*Scarf et al.*, 1970*b*, 1971]. The presence of these nonthermal particles is extremely significant for a number of reasons. For instance, the upstream flow can frequently involve a reversal of the local heat flux moment so that the region is predominantly "heated" by mechanisms originating near the earth. This makes it difficult to measure the actual interplanetary heat conduction, and the modifications can also drastically influence the local solar wind stability properties [*Forslund*, 1970]. Moreover, we know that the waves associated with upstream protons can produce local density modulations having wave periods near 20 to 60 sec, in a geocentric frame [*Scarf et al.*, 1970*b*]. These inhomogeneities are then convected downstream toward earth, and they ultimately produce a variable pressure on the entire magnetosphere. It is tempting to speculate that this large-scale upstream beam-plasma instability directly produces the pc micropulsations and short period disturbances that are correlated with changes in the solar wind flux magnitude [*Gringauz et al.*, 1971].

Since December 1967 it has been possible to monitor low-frequency interplanetary plasma turbulence with instruments on Pioneer 8, OGO 5, and Pioneer 9. These plasma wave detectors provide sensitive diagnostics that

The authors are at Space Sciences Laboratory, TRW Systems Group, Redondo Beach, California.

indicate when nonthermal plasma distributions are present, and the measurements give additional information on the magnitude and extent of the interplanetary perturbations produced by the magnetosphere. In fact, since no high sensitivity plasma probes or ac search coil magnetometers have yet been flown in deep space, these simple plasma wave instruments presently provide almost the only information on changes in the microstructure of the solar wind with increasing distance from earth. In this report we illustrate the difference between near-earth and deep space conditions using simultaneous Pioneer 9 and OGO 5 observations. We also discuss the geocentric radial variation in high-frequency turbulence, and comment on the value of the solar-terrestrial physics (STP) mission proposed in the recent NAS-NRC study [*National Academy of Sciences-National Research Council, 1971*].

OBSERVATIONS

The well documented cosmic ray event of November 18, 1968, was produced by a west limb flare and the associated interplanetary shock reached 1 AU at about 0900 UT on November 20, 1968 [*Lincoln*, 1970]. At this time Pioneer 9 was approximately 2.5 million km from earth and OGO 5 was just upstream from the bow shock. Thus, on November 20, the two spacecraft were clearly in a good position for a comparison between deep-space and near-earth observations. We therefore use these measurements to illustrate the main complexities associated with proximity to the earth's magnetosphere.

The actual positions of OGO 5 and Pioneer 9 are shown in figure 1. The OGO spacecraft detected the shock many minutes before Pioneer did, and this suggests that the shock normal was tilted far from the radial direction. *Ungstrup et al.* [1972] have examined the shock front geometry using data from OGO 5, Pioneer 9, and Explorer 35, and their report contains a comprehensive account of the analysis. The main result of interest here is the verification that the shock detected on Pioneer at 0929:30 UT was the same as the one detected near 0902 UT on OGO 5.

Figure 2 shows low-frequency electric field amplitude ranges, along with dc magnetic field measurements from the two spacecraft. The Pioneer 9 magnetometer results were supplied by Drs. C. P. Sonett, D. S. Colburn, and E. Ungstrup, and the plotted points are 28-sec averages; however, preliminary offset values were used here and the curves may still be subject to some small corrections. The OGO 5 field values in figure 2 are 1-min averages from the UCLA magnetometer, and the data were furnished by Drs. C. T. Russell and P. J. Coleman, Jr.

On November 20, the Pioneer 9 spacecraft was

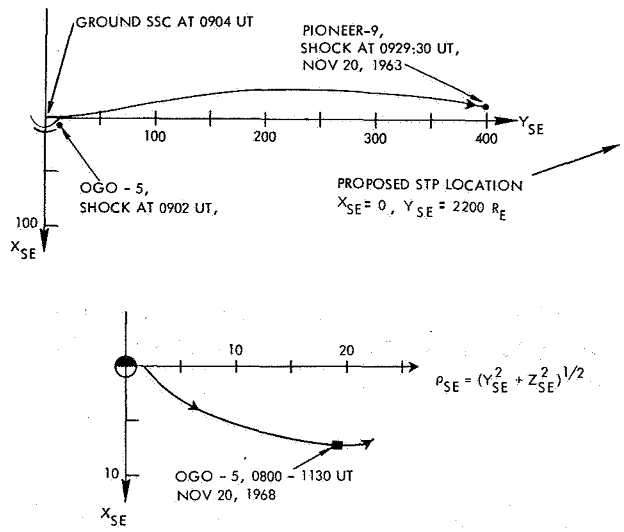

Figure 1. *(a) The Pioneer 9 trajectory from launch to November 20, 1968, and OGO 5 location at 0902 UT on November 20. We indicate here when the solar terrestrial physics (STP) probe might be located. (b) The OGO 5 trajectory for November 20, 1968, in rotated geocentric solar ecliptic coordinates.*

transmitting at its highest telemetry rate (512 bits/sec) so that the 400-Hz potential amplitude was sampled every 7 sec. However, the unbalanced and asymmetric dipole does have a sun-oriented photosheath response that produces a fairly strong spin modulation [*Scarf et al.*, 1968]. We therefore display here 5-min ranges that clearly show the true shifts in 400-Hz wave levels; near 0930 UT, the small arrows mark the actual locations of the Pioneer 9 maxima. During this period, OGO 5 was transmitting at its lowest telemetry rate (1 kilobit/sec), and the 560-Hz electric field strength was sampled once per 1.18 sec for 27.6 sec. As described by *Crook et al.* [1969], six other frequency channels are examined during successive 27.6-sec intervals and the instrument returns to the 560-Hz channel every 3.23 min. There were no special-purpose telemetry transmissions on November 20, 1968.

In figure 2, the time scales are shifted to align the interplanetary shock encounters, and the last dashed vertical line marks passage of this discontinuity. The B-field magnitude profiles displayed here are remarkably similar in the region surrounding the shock encounter. We see that the low-frequency electric field levels also changed characteristically as the shock front passed each spacecraft.

Before the shock (0910–0930 UT on Pioneer 9, 0840–0900 UT on OGO 5) the wave levels were quite low, each instrument detected a noise "spike" *at* the

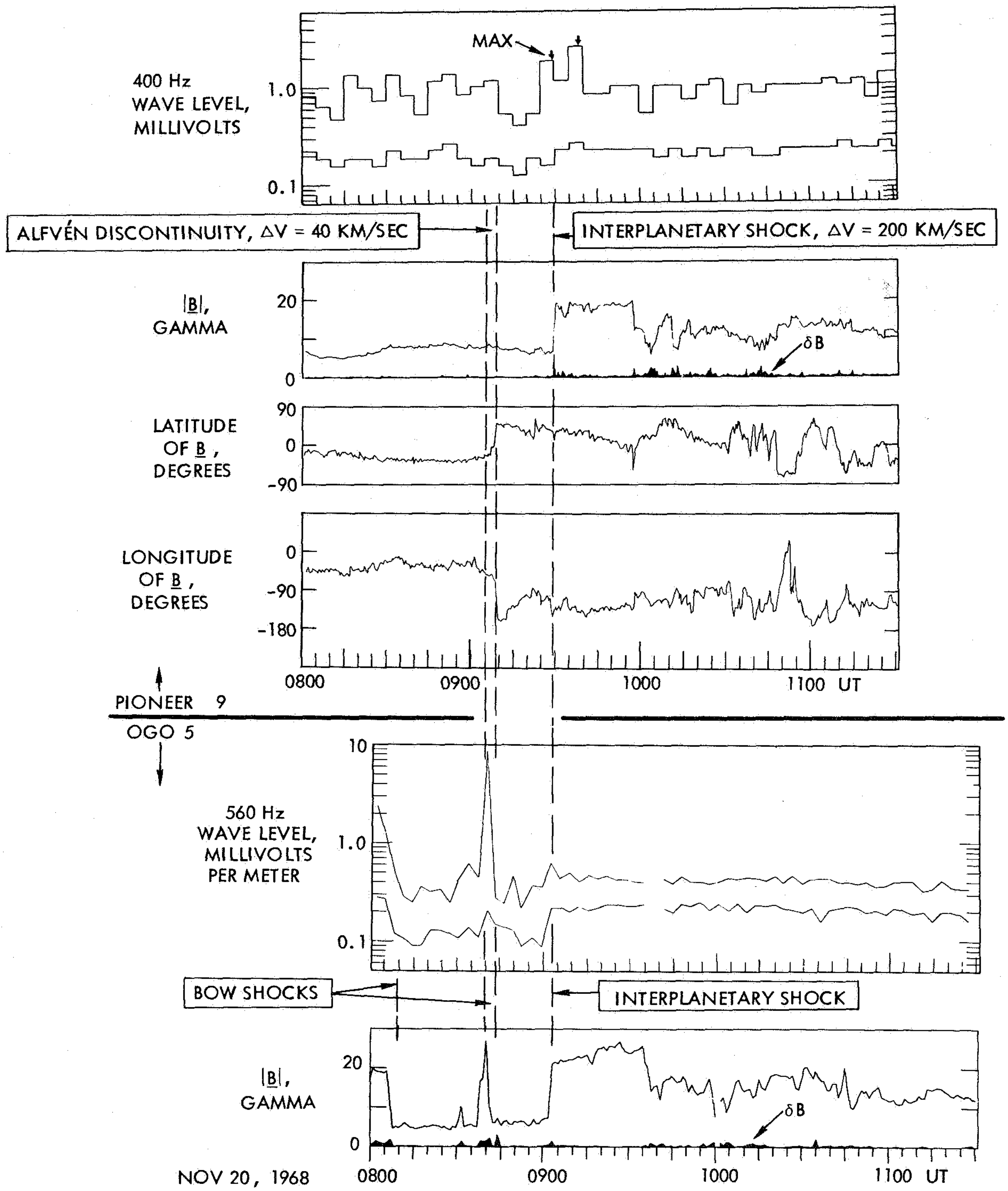

Figure 2. *Simultaneous Pioneer 9 and OGO 5 field and wave data for 0800–1130 UT on November 20, 1968. The time scales are shifted to aline the interplanetary shock encounters (third vertical dashed line). The first two vertical lines represent passage of interplanetary discontinuities; however, their appearance at the same relative times (with respect to the shock) is complete coincidence. The Pioneer 9 event at 0905–0910 UT was an Alfvén discontinuity, while the event responsible for the brief OGO 5 return to the magnetosheath (0838–0842 UT) was a contact discontinuity.*

shock encounter, and enhanced postshock noise levels were observed on both spacecraft for many hours afterward. There are, of course, some striking differences. For instance, on Pioneer 9 two noise spikes were detected in the 400-Hz channel, but only one in the OGO 560-Hz channel; however, when the second peak would have been encountered by OGO 5, the plasma wave spectrum analyzer was not sampling the 560-Hz channel output. We demonstrate below that a corresponding second noise peak was actually detected by the OGO instrument in a higher frequency channel. It is also clear that if a 1-m effective antenna length is assumed for Pioneer, then the average OGO and Pioneer wave levels in the two channels were not identical, but the relative variations were quite similar.

We have analyzed many interplanetary shock encounters on Pioneer 8, Pioneer 9, and OGO 5, and the results displayed in figure 2 are fairly typical. The shock is generally "announced" by a brief noise spike, and enhanced low-frequency plasma turbulence is then detected for an extended period after encounter [*Siscoe et al.*, 1971].

The first pair of vertical dashed lines in figure 2 marks times when additional abrupt shifts in the low-frequency turbulence levels were detected. It is evident that each spacecraft observed a change at the *same relative* time with respect to the shock encounter. One might therefore be led to speculate that some sort of precursor preceded each shock encounter by a fixed distance equal to 20 to 25 min travel time in the solar wind. However, it can be demonstrated that this interpretation is not possible; the interplanetary shock speed must have been much higher than speeds of any other discontinuities, so that fixed precursor standoff distances could not be maintained.

The basic point is that the interplanetary shock of November 20, 1968, was a strong fast-mode forward shock [see *Colburn and Sonett*, 1966, for definitions]. As noted on figure 2, the peak velocity detected by the ARC plasma probe on Pioneer 9 jumped by about 200 km/sec [*J. H. Wolfe and D. S. Intriligator*, private communication]. The field magnitude increased, and on OGO it was evident that the density also jumped as the shock passed by [*M. Neugebauer*, private communication]. Discontinuities of this type must propagate rapidly through the plasma and they must overtake slower discontinuities.

The early Pioneer 9 event at 0905–0910 UT is clearly identifiable as a slow Alfvén discontinuity, with a small velocity jump, a field rotation, and no change in $|B|$ or N. On close inspection we find that an interplanetary discontinuity also swept by OGO 5 between 0838 and 0842 UT, and this produced brief encounters with the bow shock and magnetosheath. At OGO there were negligible changes in interplanetary field latitude and longitude surrounding these brief bow shock encounters; moreover, the JPL plasma probe data show that the OGO discontinuity did *not* involve a velocity jump, but the pressure changed because of a sharp drop in the helium-to-hydrogen ratio between 0838 and 0842 UT [*M. Neugebauer*, private communication]. Thus, OGO 5 encountered a contact discontinuity about 25 min before the shock, while Pioneer encountered an Alfvén discontinuity at the same relative time. At OGO the change in Mach number apparently allowed the bow shock to move outward for a short period.

We conclude that it was complete coincidence that OGO and Pioneer both detected a discontinuity 25 min before the shock encounter. Indeed, the Pioneer 9 plasma probe also showed a large helium-to-hydrogen ratio for an extended period that ended near 0615 UT. With an effective corotation speed of 330 km/sec, this contact discontinuity would have encountered the earth near 0840 UT, in accordance with observations.

Thus, events combined fortuitously so that more order is suggested by figure 2 than actually was present in the solar wind at the time. The correct conclusions to be drawn from the observations of figure 2 are: (1) various forms of discontinuities produce large changes in low-frequency electric field turbulence levels; (2) a near-earth encounter with an interplanetary discontinuity can appear as a multiple bow shock crossing; (3) at low frequencies (400 and 560 Hz) the electric field noise enhancements generated near a standing bow shock are much more intense than those produced at a propagating interplanetary shock front.

The last conclusion is qualified by the restriction to certain frequency channels, and it is instructive to consider the measurements in all available channels. The Pioneer 9 instrument has only the 400-Hz channel, a qualitative broadband ($f \lesssim 100$ Hz) wave level indicator, and a 30-kHz channel. On OGO 5 we also have information available on levels for electric field waves with frequencies centered at 1.3, 3.0, 7.3, 14, 30, and 70 kHz. Figure 3 compares the Pioneer and OGO lower frequency outputs; the broadband wave level plotted is the equivalent amplitude for a 100-Hz sine wave, and the measurement is repeated every 56 sec.

Figure 3 reveals great complexity with rapid temporal variation in the turbulent electric field spectrum near earth. Although the magnetosheath was only encountered between 0838 and 0842 UT, large-amplitude noise enhancements were continuously detected after about 0815 UT, with peak levels in the 1.3-kHz and 3-kHz

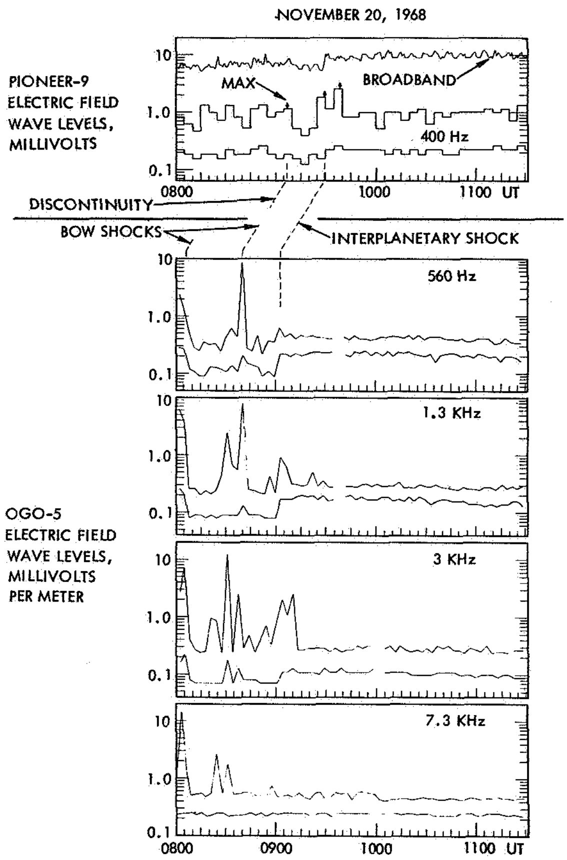

Figure 3. *Comparison of low-frequency plasma turbulence near earth and in deep space. These results indicate that: (a) the interplanetary shock electric field spectrum is peaked at a higher frequency than a standing shock spectrum; (b) large amplitude electrostatic turbulence develops throughout the upstream region; (c) the source of this turbulence is swept away through interplanetary shock.*

channels. We interpret this as evidence that suprathermal protons with $E \simeq 5$ keV were present, but since no high-sensitivity plasma probes were operating on OGO during the November 20 interval, there is no direct information on this point. However, for other periods it has been shown that enhanced midfrequency electric field turbulence in the upstream region is correlated with the presence of suprathermal protons [*Scarf et al.,* 1970*b*].

The OGO 5 observations at the interplanetary shock itself clearly reveal the inadequacy of the simple Pioneer 9 instrument with a single 400-Hz channel. It is evident from figure 3 that near the standing bow shocks (about 0805, 0838, and 0842 UT) the output from the 560-Hz channel is fairly representative; however at the propagating shock front the 560-Hz turbulence level is significantly lower than that detected in the 1.3- and 3-kHz channels.

These bandpass channel responses suggest a shift in the plasma turbulence spectrum with shock speed past the spacecraft, but analysis of the special purpose telemetry or waveform output is needed if this suggestion is to be verified. Unfortunately, no special purpose transmissions were available on November 20, 1968, and this statement applies for a fair number of additional interplanetary shock encounters near apogee. The OGO 5 special-purpose data link suffered a degradation early in the flight and after mid-April 1968 the highest quality broadband data were acquired at moderate spacecraft altitudes. For this reason, we turn to an early interplanetary shock encounter to describe the turbulent electric field spectrum.

Near 1320–30 UT on April 5, 1968, OGO 5 was outbound in the magnetosheath with $r \simeq 21\ R_e$ and local time $\simeq$ 0630. An interplanetary shock swept by at 1326:40 UT, and the spacecraft was suddenly in the solar wind. The lowest panel in figure 4 shows the

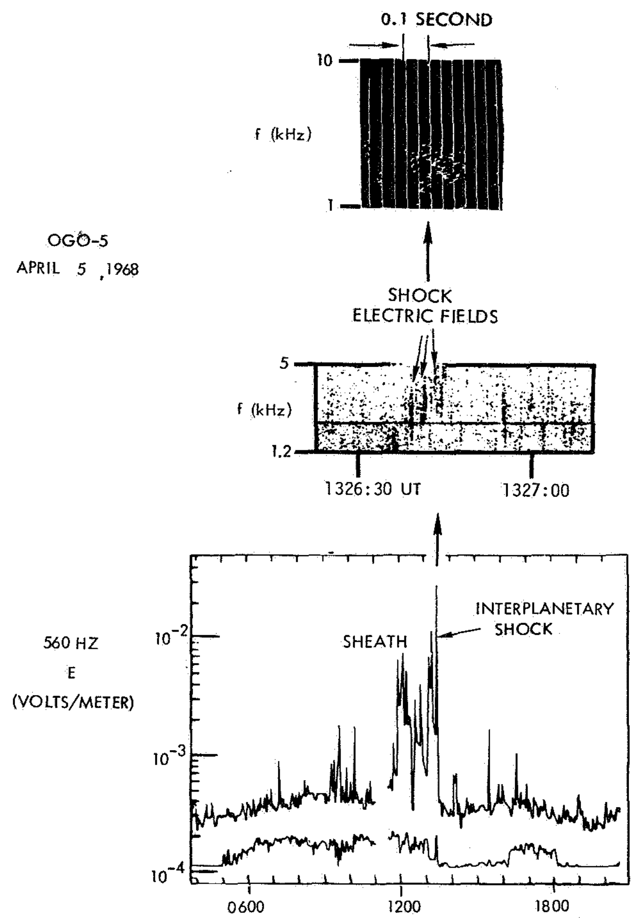

Figure 4. *High-resolution spectral analysis of electrostatic turbulence at an interplanetary shock front.*

560-Hz channel ranges, and the central panel contains a broadband frequency-time diagram of the shock turbulence (the horizontal line is a spacecraft interference tone at 2.46 kHz). At the top of figure 4 we display individual spectral sweeps taken every 50 msec in the neighborhood of the interplanetary shock.

It can be seen that the spectral peak in the April 5 shock spectrum is at a frequency well above 400 Hz or 560 Hz, consistent with the inference drawn from the bandpass channel data of figure 3. *Fredricks et al.* [1968; 1970*a, b*] have analyzed a number of bow shock encounters in a similar manner, and they found generally lower turbulence frequencies for these standing shocks. It does appear that the turbulent electric field spectrum for a propagating shock is similar to that observed at the bow shock, but that it is shifted in frequency. This suggests that Doppler effects are important, and it tells us that the Pioneer 8 and 9 low-frequency channels give incomplete information on electrostatic wave generation at discontinuities.

Before leaving the discussion of the lower frequency waves, we return to figure 3 and comment briefly on the postshock OGO 5 observations. The first point to note is that a double noise enhancement, with the two peaks separated by about 8 min, is evident in both sets of data. On Pioneer 9 the 400-Hz channel was sampled uniformly and the first noise spike at 0929:45 UT was followed by a somewhat larger one at 0937:45 UT. Similarly, the first 560-Hz noise enhancement was detected at 0902:44 UT, and a subsequent 3-kHz peak was found at 0910:06 UT. Thus it appears that this interplanetary shock did have a complex turbulence profile with two distinct enhancements.

The final point of interest concerns the postshock absence of sporadic 1.3- and 3-kHz noise enhancements. If these bursts are actually associated with upstream protons as suggested earlier, then the observations would seem to suggest that the suprathermal proton halo is swept away by the advancing shock front.

A similar effect is found when we examine the high-frequency electron-mode wave levels. The 30-kHz electric field ranges of November 20, 1968, for Pioneer 9 and OGO 5 are shown in figure 5. In the initial report on Pioneer 8 [*Scarf et al.*, 1968] it was observed that an interference problem associated with the sheath and the unbalanced dipole sensor degraded the inflight sensitivity of the 22-kHz channel. On Pioneer 9 a similar problem was present at 30 kHz and, as shown, the inflight threshold is quite high. Nevertheless, the OGO 5 plasma wave instrument did detect many bursts with $E \gtrsim 700 = \mu V/m$ between 0800 and 0900 UT on November 20, and these should also have been detectable

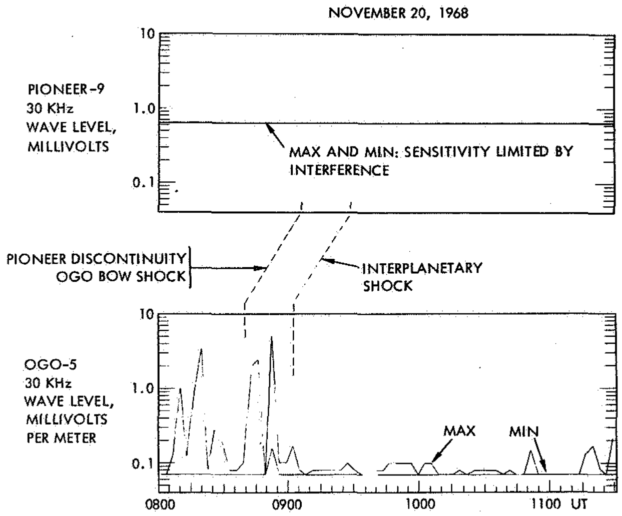

Figure 5. *Comparison of high-frequency noise bursts near earth and in deep space. Although the Pioneer 9 30-kHz sensitivity is limited by inflight interference many of the OGO 5 signals would have been detectable on Pioneer if they were present at 400 R_e.*

on Pioneer 9 if they were present in deep space. The absence of any such signals suggests that the 30-kHz noise bursts are actually a near-earth phenomenon.

Detailed analysis tends to confirm this conjecture. In a recent study [*Scarf et al.*, 1971] it was demonstrated that these bursts have wave frequencies nearly equal to the local electron plasma or upper hybrid frequencies. It was also shown that the oscillations are produced when nonthermal electrons with energies greater than 700 to 800 eV flow upstream.

One aspect of the data from figure 5 supports this interpretation; that is, the abrupt end to the OGO 5 high-frequency wave activity at about 0900–0905 UT can be attributed to the shock front sweeping away these nonthermal upstream electrons. Indeed, during the 0905–1100 UT period the 30 kHz wave activity was about as minimal as we have ever seen it in the upstream solar wind, but toward the end of the period shown in figure 5 somewhat larger signals were detected.

The Pioneer 9 near-earth observations at 30 kHz also tend to confirm this interpretation of the high frequency bursts. The spacecraft entered the magnetosheath at about 1530 UT on November 8, 1968, and the bow shock region was traversed between 0110 and 0315 UT on November 9, when Pioneer was in an engineering format related to a spin-axis reorientation. The lower part of figure 6 shows the near-earth trajectory in rotated geocentric solar ecliptic coordinates, and 56-sec 30 kHz wave level ranges for the period 0315–0645 UT

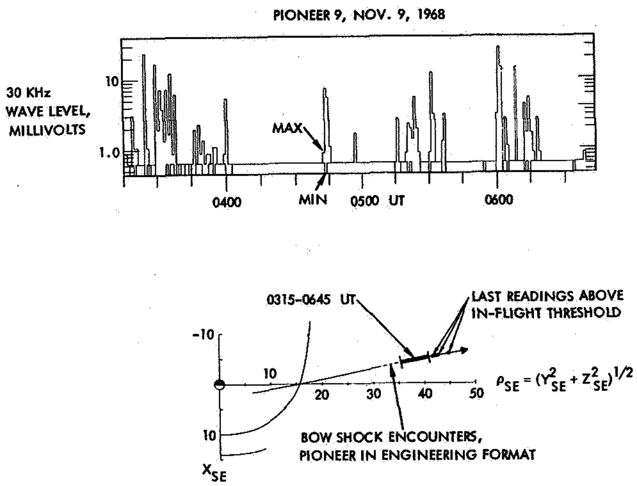

Figure 6. *High-frequency observations on Pioneer 9 in the near-earth region. Except for the four additional points designated on the trajectory plot, the data in the top panel represent all the above-background 30-kHz measurements made on Pioneer 9. We conclude that high-frequency activity of this type is associated with proximity to the earth and bow shock.*

on November 9 are displayed in the top panel. If we use an effective antenna length of about 1 m for Pioneer, it is clear that on November 9 the Pioneer instrument detected many 30 kHz noise bursts at least as strong as those measured by OGO 5 on November 20. However, these readings are virtually the *only* above-threshold values detected by the Pioneer 9 instrument after launch. In fact, only four additional 56-sec segments had above-background readings; their locations are marked on the trajectory plot. Although the inflight threshold for the 30 kHz channel of Pioneer 9 is unfortunately quite high, it can be stated that *all* detectable activity was confined to the region within 50 R_e of earth. This again strongly suggests that the earth's magnetosphere and bow shock are the sources for the nonthermal electrons that produce these waves.

DISCUSSION

We have seen that characteristic changes in low-frequency interplanetary plasma wave turbulence levels are associated with the passage of solar wind discontinuities such as fast forward shocks, and Alfvén and contact discontinuities. Striking changes in the electric field noise levels are also associated with reverse and slow shocks, and accounts of these observations will be reported elsewhere. These results have a number of significant physical implications, and several examples can readily be cited. For instance, *Dryer* [1970] and *Eviatar and Dryer* [1970] recently pointed out that turbulent conductivity can drastically affect local conditions near interplanetary shocks and driver pistons. In another area, *Lanzerotti and Robbins* [1969] discussed the effects of electric field turbulence on energetic solar proton and alpha partical distributions. The plasma turbulence may also provide interplanetary acceleration, cross-B diffusion, and quenching of thermal anisotropies and heat flux.

One severe difficulty associated with the experimental study of these wave-particle interactions from an earth orbiter arises because the earth itself provides significant fluxes of nonthermal particles that generate intense plasma turbulence in the upstream region. We have illustrated these effects here by analyzing simultaneous Pioneer 9 and OGO-5 data for the period surrounding the interplanetary shock encounter of November 20, 1968.

The problem raised by the upstream noise halo is solved if the instruments are carried far enough from earth, but missions using conventional heliocentric probes such as Pioneer 9 face a different set of problems. The earth-spacecraft range continually increases, and after a few months the tracking schedule necessarily has large gaps in time, with low information rates between the gaps. Moreover, the deep space measurements are not necessarily well correlated with terrestrial events when the spacecraft-earth distance becomes large.

The solar-terrestrial physics (STP) mission is designed so that a probe will be located at a fixed but large distance from earth; a possible location is indicated in figure 1. At such a range, high bit rates and continuous tracking should be available, and no upstream effects will be present. Thus, the STP probe can provide a suitable platform for the study of interplanetary wave-particle interactions, and experiments on this spacecraft could also measure true interplanetary heat conduction and other subtle features of the undisturbed solar wind. Finally, a probe stationed in this location would be able to detect corotating interplanetary disturbances well before the events reach earth, and the mission would therefore provide firm information on the cause and effect relations in solar-terrestrial physics.

ACKNOWLEDGMENTS

We are grateful to Drs. D. S. Colburn, P. J. Coleman, Jr., D. S. Intriligator, M. Neugebauer, C. T. Russell, C. P. Sonett, E. Ungstrup, and J. H. Wolfe for allowing us to display and describe their field and plasma data. This research was supported by the National Aeronautics and Space Administration under Contracts NASW-2113, NAS5-9278 (OGO Project at GSFC) and NAS2-4673 (Pioneer Project at ARC).

REFERENCES

Anderson, K. A.; Harris, H. K.; and Paoli, R. J.: Energetic Electrons In and Beyond the Earth's Outer Magnetosphere. *J. Geophys. Res.*, Vol. 70, 1965, p. 1039.

Anderson, K. A.; Energetic Electrons of Terrestrial Origin Upstream in the Solar Wind. *J. Geophys. Res.*, Vol. 73, 1968, p. 2387.

Colburn, D. S.; and Sonett, C. P.: Discontinuities in the Solar Wind. *Space Sci. Rev.*, Vol. 5, 1966, p. 439.

Crook, G. M.; Scarf, F. L.; Fredricks, R. W.; Green, I. M.; and Lukas, P.: The OGO-V Plasma Wave Detector; Instrumentation and In-Flight Operation. IEEE Trans. Geosci. Elec., GE-7, Vol. 2, 1969, p. 120.

Dryer, M.: Some Effects of Finite Electrical Conductivity On Solar Flare-Induced Interplanetary Shock Waves. *Cosmic Elec.*, Vol. 1, 1970, p. 348.

Eviatar, A.; and Dryer, M.: Finite Conductivity and Interplanetary Piston-Driven Shock Waves. *Cosmic Elec.*, Vol. 1, 1970, p. 371.

Fairfield, D. H.: Simultaneous Measurements On Three Satellites and the Observation of the Geomagnetic Tail at 1000 R_e. *J. Geophys. Res.*, Vol. 73, 1968, p. 6179.

Forslund, D. W.: Instabilities Associated with Heat Conduction in the Solar Wind and Their Consequences. *J. Geophys. Res.*, Vol. 75, 1970, p. 17.

Fredricks, R. W.; Kennel, C. F.; Scarf, F. L.; Crook, G. M.; and Green, I. M.: Detection of Electric-Field Turbulence in the Earth's Bow Shock. *Phys. Rev. Lett.*, Vol. 21, 1968, p. 1761.

Fredricks, R. W.; Coroniti, F. V.; Kennel, C. F.; and Scarf, F. L.: Fast Time-Resolved Spectra of Electrostatic Turbulence in the Earth's Bow Shock. *Phys. Rev. Lett.*, Vol. 24, 1970*a*, p. 994.

Fredricks, R. W.; Crook, G. M.; Kennel, C. F.; Green, I. M.; Scarf, F. L.; Coleman, P. J.; and Russell, C. T.: OGO-5 Observations of Electrostatic Turbulence in Bow Shock Magnetic Structures. *J. Geophys. Res.*, Vol. 75, 1970*b*, p. 3751.

Freeman, J. W., Jr.; Balsiger, H.; and Hills, H. K.: Preliminary Results From the Lunar Ionosphere Detector. *Rice Univ. Preprint*, Jan. 1970.

Gringauz, K. I.; Solomatina, E. K.; Troitskaya, V. A.; and Shchepetnov, R. V.: Variations of Solar Wind Flux Observed by Several Spacecraft and Related Pulsations of the Earth's Electromagnetic Field. *J. Geophys. Res.*, Vol. 76, 1971, p. 1065.

Intriligator, D. S.; Wolfe, J. H.; McKibbin, D. D.; and Collard, H. R.: Preliminary Comparison of Solar Wind Plasma Observations in the Geomagnetospheric Wake at 1000 and 500 Earth Radii. *Planet. Space Sci.*, Vol. 17, 1969, p. 321.

Lanzerotti, L. J.; and Robbins, M. F.: Solar Flare Alpha to Proton Ratio Changes Following Interplanetary Disturbances. *Solar Phys.*, Vol. 10, 1969, p. 212.

Lincoln, J. V.: Data on Cosmic Ray Event of November 18, 1968 and Associated Phenomena. *Report UAG-9, World Data Center A*, April, 1970.

Mariani, F.; and Ness, N. F.: Observations of the Geomagnetic Tail at 500 Earth Radii by Pioneer 8. *J. Geophys. Res.*, Vol.74, 1969, p. 5633.

National Academy of Sciences-National Research Council Report: Priorities for Space Research, 1971-1980, March, 1971.

Ness, N. F.; Scearce, C. S.; and Cantarano, S.: Probable Observations of the Geomagnetic Tail at 10^3 R_e by Pioneer 7. *J. Geophys. Res.*, Vol. 72, 1967, p. 3769.

Scarf, F. L.; Crook, G. M.; Green, I. M.; and Virobik, P. F.: Initial Results of the Pioneer 8 VLF Electric Field Experiment. *J. Geophys. Res.*, Vol. 73, 1968, p. 6665.

Scarf, F. L.; Green, I. M.; Siscoe, G. L.; Intriligator, D. S.; McKibbin, D. D.; and Wolfe, J. H.: Pioneer 8 Electric Field Measurements in the Distant Geomagnetic Tail. *J. Geophys. Res.*, Vol. 75, 1970*a*, p. 3167.

Scarf, F. L.; Fredricks, R. W.; Frank, L. A.; Russell, C. T.; Coleman, P. J., Jr.; and Neugebauer, M.: Direct Correlations of Large Amplitude Waves with Suprathermal Protons in the Solar Wind. *J. Geophys. Res.*, Vol. 75, 1970*b*, p. 7316.

Scarf, F. L.; Fredricks, R. W.; Frank, L. A.; and Neugebauer, M.: Non-thermal Electrons and High Frequency Waves in the Solar Wind: Part 1, Observations, submitted to *J. Geophys. Res.*, 1971.

Siscoe, G. L.; Scarf, F. L.; Intriligator, D. S.; Wolfe, J. H.; Binsack, J. H.; Bridge, H. S.; and Vasyliunas, V. M.: Evidence for a Geomagnetic Wake at 500 Earth Radii. *J. Geophys. Res.*, Vol. 75, 1970, p. 5319.

Siscoe, G. L.; Scarf, F. L.; Green, I. M.; Binsack, J. H.; and Bridge, H. S.: Very-Low-Frequency Electric Fields in the Interplanetary medium: Pioneer 8 *J. Geophys. Res.*, Vol. 76, 1971, p. 828.

Ungstrup, E.; Colburn, D. S.; and Sonett, C. P.: in preparation, 1972.

Wolfe, J. H.; Silva, R. W.; McKibbin, D. D.; and Mason, R. H.: Preliminary Observations of a Geomagnetic Wake at 1000 Earth Radii *J. Geophys. Res.*, Vol. 72, 1967, p. 4577.

DISCUSSION

Roelof Is my memory correct for this particular flare, the November 18, 1968, flare that it had a west limb origin, about 78°W.?

Scarf Yes, this was a west limb flare. The arrival of this flare at the earth was accompanied by an increase in the proton flux that Lanceratti has attributed to a local acceleration process (private communication). I don't know if this describes it any further but the data are tabulated by Virginia Lincoln; this is the flare that originated on the 18th because of the big cosmic ray event and the shock arrived at the earth on the 20th.

Roelof So if we go back to the geometries presented by Hundhausen then this is a very broad sort of a bubble (being from a west limb flare) to be detectable as a shock at earth.

Scarf Well, it arrived in a very strange way, i.e., at OGO before Pioneer. So it certainly is not in the direction of corotation, it's highly oblique.